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Making forgotten information available: An early study on the Afghanistan Mountain Salamander *Paradactylodon* (*Afghanodon*) *mustersi* (Smith, 1940) (Caudata: Hynobiidae)

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Dedication. *We dedicate this paper to all enthusiastic students, teachers and researchers in Afghanistan to encourage them devoting themselves to the study of biodiversity of their country, as did the author of the study on the Afghan Mountain Salamander already nearly six decades ago.*

Abstract. The first study after the official species description of the endemic Afghanistan Mountain Salamander *Paradactylodon* (*Afghanodon*) *mustersi* (Smith, 1940) was published in Kabul, Afghanistan, and only in Dari Persian. We, therefore, provide here an English translation of this paper, together with so far unpublished background information on this rare and endangered amphibian, and on the former scientific German-Afghan cooperation project from the 1960s in the framework of which this study had been performed.

Key words. *Batrachuperus*, Central Asia, Hindu Kush, ecology, conservation, history.

INTRODUCTION

The hynobiid Afghanistan Mountain Salamander *Paradactylodon* (*Afghanodon*) *mustersi* (Smith, 1940) is endemic in a relatively small part of northeastern Afghanistan (Provinces of Ghazni, Kabul, Parwan, and Wardak; see Böhme 1982; Wagner et al. 2016; Ahmadzadeh et al. 2020). However, one dubious record of an urodelan amphibian (very likely a *Paradacytlodon*) is also known from the Chitral valley of Pakistan (Wall 1911). This means, the species is strictly endemic to the Hindu Kush mountain range and represents thus one of the most endangered amphibian species in the world (Stuart et al. 2008); according to the IUCN Red Data List of Threatened Species (Papenfuss et al. 2004), this species falls under the category "Critically endangered". Its first description (Smith 1940) had considered it the westernmost species of the otherwise East Asian (Chinese) genus *Batrachuperus* Boulenger, 1878. Up to date, there are only few mostly short, semi-popular or research papers on this rare salamander, particularly on its life habits or biology (Mertens 1970; Seufer 1974; Van Meeuwen 1977; Sparreboom 1977, 1978; Böhme 1982; Reilly 1983; Jablonski et al. 2020).

However, it is not well known that an early study of its ecology and biology after the official species description (Smith 1940) was performed by Storai Nawabi when she was a student of Prof. Dr. Ernst Kullmann (1931–1996). It was published in an Afghan journal named "Science" which had appeared in Kabul (Nawabi 1965) and was written in Dari Persian, a dialect of Farsi used in western, central and northeastern Afghanistan.

The late Dr. Josef Eiselt (1912–2001), herpetologist at the Vienna Natural History Museum, became interested in this hardly accessible manuscript when he started to work on this group of urodelans himself together with a colleague (Eiselt & Steiner 1970) by describing a new presumed congener from Iran which they named *Batrachuperus persicus* Eiselt & Steiner, 1970 (see Schmidtler & Schmidtler 1971). Thanks to his efforts, a handwritten translation of the manuscript into German was performed which made the information on this rare salamander species available at least to the German speaking scientific community so that for instance it could be used for Böhme's (1982) notes on this species. The description of another species from NE Iran, viz. *B. gorganensis*, by Clergue-Gazeau & Thorn (1978), forced more interest in these westernmost hynobiids (e.g., Stöck 1999) and finally led to a generic partition, with the erection of a new genus *Paradactylodon* Risch, 1984 for *B. gorganensis*. This concept was adopted by numerous authors to accommodate the three western *Batrachuperus* taxa as

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opposed from their Chinese/Tibetan congeners for nearly three decades (e.g., Zhang et al. 2006; Raffaëlli 2007; Poyarkov 2010; Ahmadzadeh et al. 2011). Dubois & Raffaëlli (2012) and Dubois et al. (2021), however, regarded Risch's (1984) name, although published under A. Dubois' editorship, as incompatible with the regulations of the Code (ICZN 1999) and replaced it by two new genera, which were extremely shortly, only in a tabular form diagnosed, viz. *Iranodon* Dubois & Raffaëlli, 2012 for the two Iranian taxa and the monotypic *Afghanodon* Dubois & Raffaëlli, 2012 for the Afghan representative. Although the calculated age of the split between these two clades is 22.72 Mya (Ahmadzadeh et al. 2020) and thus would justify generic separation, we follow these authors in maintaining *Paradactylodon* as the genus name, the more as Frost (2021) has convincingly argued for the availability of *Paradactylodon* again. If it is warranted to equip the Iranian (*P. gorganensis* is nested within *persicus*!) and the Afghan species with an own monotypic genus-group name each, a subgeneric distinction would be sufficient and beneficial for nomenclatural stability. Such a distinction could also highlight the endemicity of these divergent clades. *Iranodon* should then be endemic for the Iranian Alborz and Talysh Mountains, and *Afghanodon* for (according to our current knowledge) the Afghan part of the Hindu Kush Mountains.

In this paper, we shall provide an English translation of Nawabi's (1965) paper, based on the handwritten German version, in order to make the early, rare and local information on this poorly known and critically endangered salamander available to the scientific community, the more as neither this work nor the note by Böhme (1982) are cited in the recent checklist of the Afghan herpetofauna by Wagner et al. (2016). A facsimile copy of the original Farsi-written paper is also provided as an appendix. We also provide some information on the German-Afghan cooperation (partnership contract between the universities of Cologne and Bonn on the one side, and of Kabul on the other) in the 1970s, to illustrate the intellectual climate in which the zoological research on the fauna of Afghanistan flourished in those days. The German projects in Afghanistan, mainly the foundation of a zoological garden and a zoological museum nearby were by-products, but not official parts of the mentioned university partnership (Kullmann 1970; Naumann & Nogge 1973; Nogge 2010). It was the zoo in Kabul which brought Storai Nawabi in contact with Prof. Ernst Kullmann who later became her academic supervisor in Bonn. The first Dari-written study from Afghanistan carried out and published by her (Nawabi 1965) remained largely unknown, obviously due to linguistic reasons. We here provide the first English translation of the handwritten German version initiated by J. Eiselt (some minor additions for better understanding being in square brackets).

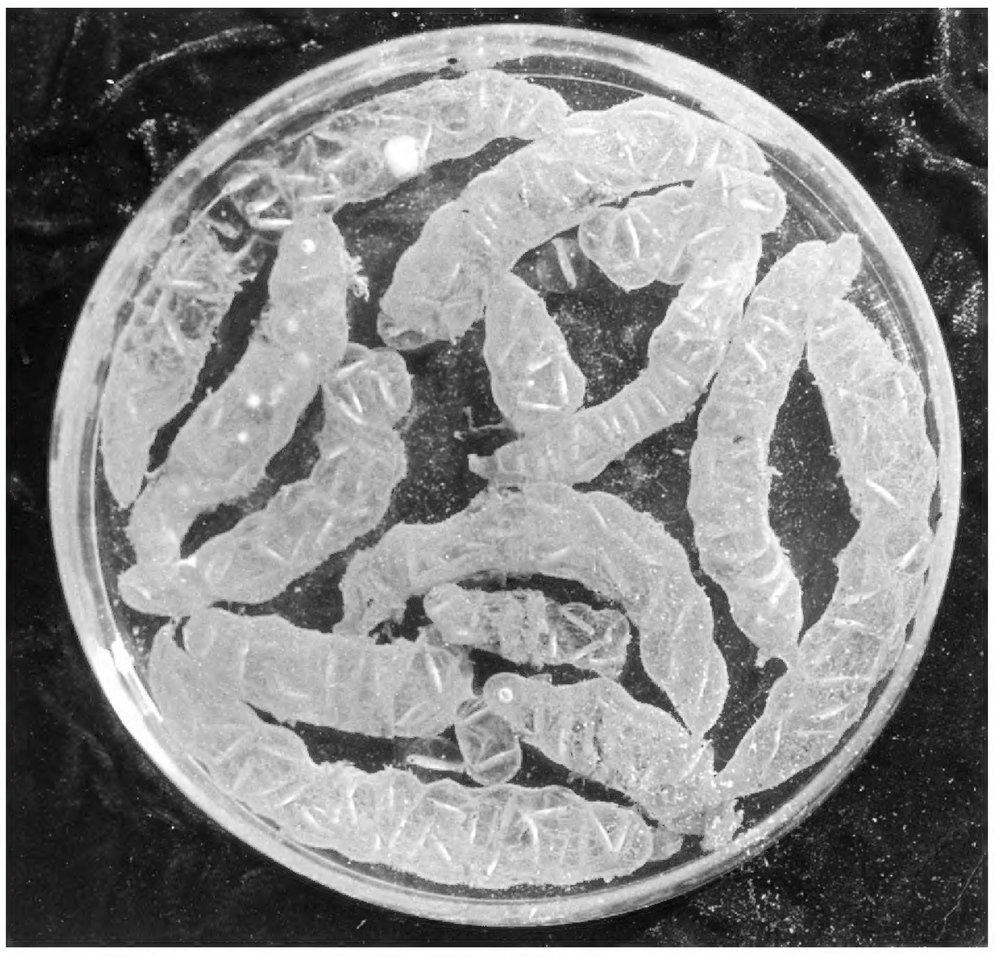


Fig. 1. (Fig. 2 in the original paper). Egg sacs of *Paradactylodon* (*Afghanodon*) *mustersi* with developing larvae. Photo: Storai Nawabi

English translation
A rare amphibian species in Afghanistan

Among the animals occurring in Afghanistan amphibians are hardly explored. Amphibians are vertebrates and form a group between fishes and reptiles. Amphibian larvae are aquatic and breathe with gills, but the adults can also live on land because they get through their metamorphosis a new respiratory system. The gills are reduced and lungs are developed.

As far as currently known, there are more than 400 bird species in Afghanistan, but only four species of amphibians. As a reason (for this poor amphibian fauna) it could be assumed that Afghanistan is a dry country where large parts are very warm in summer, but very cold in winter, particularly above 1500 m [above sea level]. *Moreover several rivers are shallow and dry completely out in summer. Some rivers, however, have such a steep gradient that they are, from this reason alone, unsuitable for such animals.*

Three of the amphibians belong to the group Anura (tailless amphibians), and two of them are frogs, the scientific names of which are (1) Rana ridibunda, *and (2)* Rana sternosignata. *The third one is a toad and is called* Bufo viridis. *It is largely distributed and can be found on creeks and in the mountains, as well as in cities and is even common and present in large numbers in Kabul.*

Only one species of the group of Urodela (tailed amphibians) which is called Batrachyperus [sic] mustersi, *has been found in 1935 and was described by Smith in 1940 as a new species (Contribution to the herpetology of Afghanistan. Annals and Magazine of Natural History, ser. II. Vol 5, 382–384).*

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Batrachyperus mustersi *belongs to the Hynobiidae, which are partitioned in five groups:*

(1) Batrachyperus *has two subgroups:* B. pinchoni, *and* B. tibetanus, *which has only been found in the mountains of South China.*
(2) Hynobius *with nine subgroups. One of them is* Hynobius keyserlinglii [sic], *occurring in Kamtschatka, Mongolia, Mandshuria, reaching Europe at the Ural Mts.*
(3) Onychodactylus *has two subgroups:* O. yaponicus [sic] *and* O. fischeri, *ranging from Korea to Japan.*
(4) Pachypalaminus *living in Japan.*
(5) Ranodon *one species of which,* Ranodon sibiricus, *occurs in western China and Turkestan.*

The family Hynobiidae has been found only in Asiatic countries and represents the early urodelans. Representatives of this family are characterised by their teeth, they are called angle-toothed urodelans. Many of them have four toes each at the fore- and hindlimbs.

B. mustersi *has been found so far only in Paghman, until now no other place has been recorded.*

During all student excursions of our Institute numerous water-breeding animals have been collected. So far, their development, though potentially quite interesting, has not yet been studied in detail.

We found B. mustersi *in a tributary or side arm of the Paghman River which runs through the Paghman valley. The area is water-rich and partly forested. Because the river itself is fast-running, its side arms provide better conditions for the development of the eggs. The eggs are forming long sac-like structures. One end is fixed at the lower part of a stone and in direct contact with water, while in* Hynobius *the eggs are deposited on plants at the water surface. The shape of the egg sacs can be seen in Fig. 2; remarkable is that one end of this structure is pointed. Each egg consists of a gelatinous substance. Interiorly is a germinal disc which grows in the course of its development until the larva hatches. Such a round egg measures 12 mm in diameter, the larva 13 mm. The following table provides some measurements:*

Values found on 17 June 1965 per egg sac

Lengt	*Width*	*Number of eggs*
15 cm	*2.2*	*31*
13 cm	*2.2*	*25*
13 cm	*2.2*	*27*
10,5 cm	*2.2*	*17*
10 cm	*1.8*	*30*
10 cm	*2.4*	*27*
8 cm	*1.6*	*25*
8 cm	*2*	*21*
7 cm	*2.4*	*19*
6 cm	*2.4*	*13*

Not all of the eggs within one sac are finishing their development, some being unfertilized, some dying during the embryonic development and some being viable. For example: Out of 24 eggs, six remained unfertilized, five remained in the embryonic stage, and 13 hatched. The young larvae which leave the egg sac lie on the lower part of the bottom.

We made the observations of this procedure under artificial conditions. Whether the procedure would take place in the same way also under natural conditions, is not known. With our (limited) possibilities we were unable to keep the larvae alive, because they need sufficient amounts of oxygen and fresh water. Moreover, we are still not sure which kind of food they need. Until now, we were unable to collect larvae at exactly those places where we had found the egg sacs. We assume that the hatched larvae move to the Paghman River itself.

Young larvae have a fish-like appearance (Fig. 3) and are 14–16 mm long immediately after hatching. The whole body with tail, except of head and breast, is surrounded by an uninterrupted median fin seam which is reduced with the further development of the larva. Traces of this seam are, however, still visible in older larvae and in freshly metamorphosed animals. The larvae have three pairs of juxtaposed gills. According to our studies, the gills are still persisting in larvae up to 8.5 cm in size. With the reduction of the gills the lungs start functioning, but the beginning of the metamorphosis stage itself was not yet observed. In very young larvae, we observed filiform appendices closely behind the eyes which are subsequently lost again. These structures serve for maintaining the larva's equilibrium in the water (Fig. 3). At the beginning of the larval stage, close to the gills, the forelimbs start to develop, followed by the hind limbs later on, so that in larvae of 8.5 cm length as in Fig. 4 the gills as well as the four extremities are visible.

The larvae have a whitish ground color with small brown flecks scattered over the entire body including the fin seams, which become scarcer towards the underside and are invisible on breast and belly. During metamorphosis, dark green to brownish spots are increasing on the dorsum. The developed larvae are silvery-brown at their undersides with a greenish shine and have often ventral silver-colored spots which are not well visible in the metamorphosed animal but can persist on the lower jaw. The outer shape of the animal looks somewhat flattened and is laterally segmented (Fig. 5). An adult specimen may reach a length of 21.5 cm, the tail, with 10.5 to 11 cm, making approximately the half of the total length. Our further investigations lead to the result that after their egg deposition, the adults do not return to a

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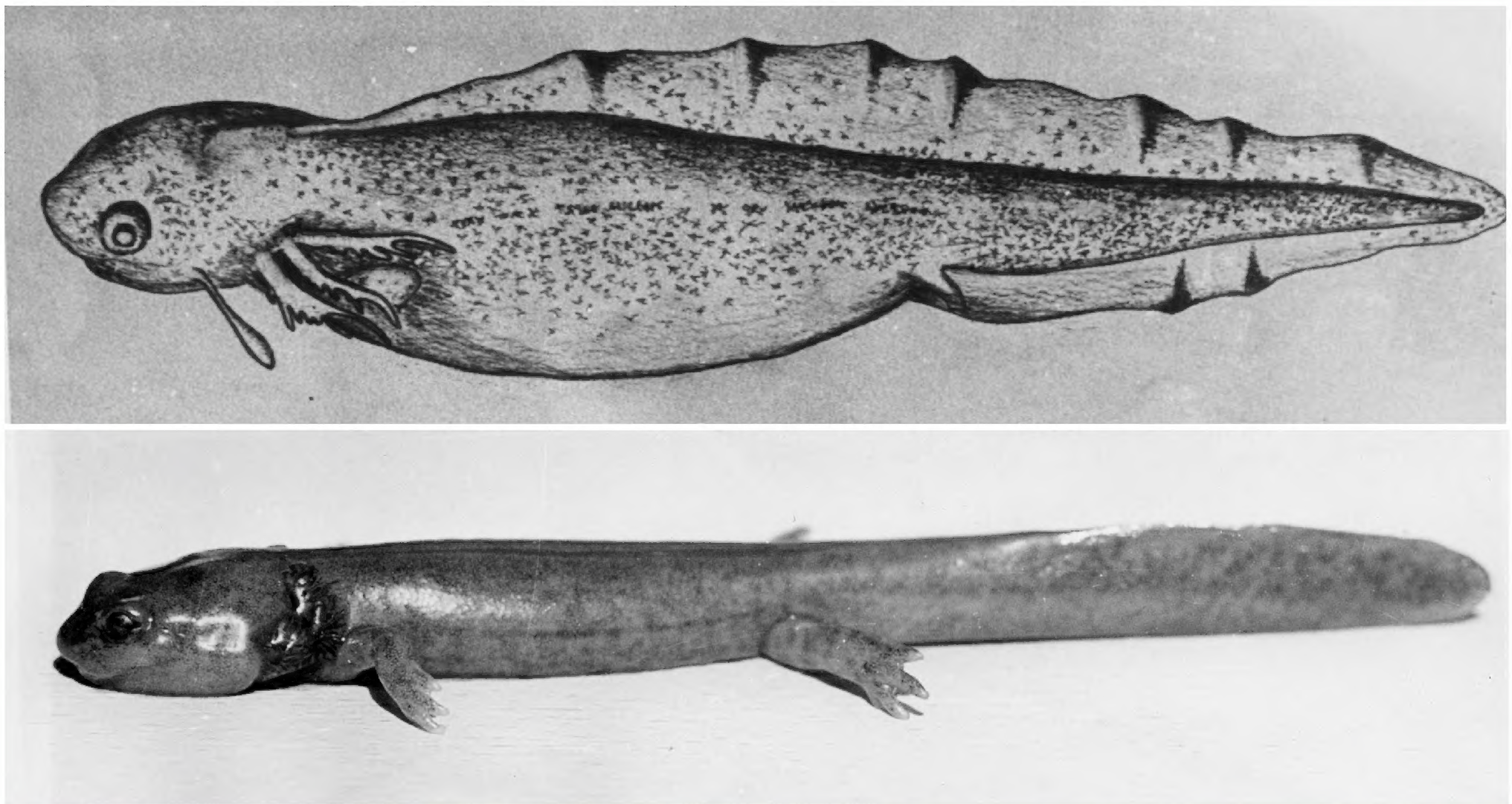


Fig. 2. (Figs 3–5 in the original paper). Young larva (above), larva ripe for metamorphosis (middle), and adult specimen (below). Drawing and photos: Storai Nawabi

terrestrial habitat but stay permanently under water. We emphasize this here because we found the salamanders exclusively in the water, submersed under stones. This was the result of our investigations as far as we could perform them in the frame of our possibilities, and which we plan to continue.

Fig. 1. Region where we found B. mustersi

Fig. 2. Eggs of these animals and their egg sacs which contain already larvae

Fig. 3. Freshly hatched larva

Fig. 4. Developed larva with gills and extremities

Fig. 5. Adult B. mustersi

My cordial thanks for his support go to Dr. Kullmann

DISCUSSION

The above text must be seen today against its historical background: It was written 57 years ago by a young Afghan female student in Kabul, Afghanistan, who carried out a study including some fieldwork on the only urodelan species of her country, supervised by a German zoologist. In fact, she was the first Afghan student who published a herpetologically-related paper from Afghanistan.

The nomenclature she used is that of her time. The subject of her study is now, after the discovery of a related species in Iran, and as stated already in the introduction, assigned to the genus *Paradactylodon* Risch, 1984, which was partitioned again and even replaced by

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Fig. 3. Adult specimen of *Paradactylodon* (*Afghanodon*) *mustersi* kept alive in Bonn. Photo: W. Böhme

two names, by Dubois & Raffaëlli (2012), the one for our species here being *Afghanodon*. The genus concept is to unite (monophyletically) related species, thus giving information on phylogenetic relationship, while monotypic genera are merely a prefix of a single species name (Richter 1943). Here, we maintain *Paradactylodon* and group *Afghanodon* only as a subgenus of the Afghan endemic brook salamander which is sufficient to express its long evolutionary isolation from the Iranian congener. One character in the short and only tabular diagnosis of *Afghanodon* and its Iranian fellow (sub)genus *Iranodon* was an abbreviation for the "adaptability in terrarium": HAT (high) for the latter, and LAT (low) for the former, certainly a weak diagnostic character for a new genus name. Moreover, several reports have shown, that also *P.* (*A.*) *mustersi* is well adaptable to captive conditions (Mertens 1970; Seufer 1974; Sparreboom 1977, 1978; Böhme 1982) and yielded several natural history data (food intake by tongue protrusion, partial terrestriality, reproductive behavior) obtained by these authors from specimens kept in aqua-terraria.

The other amphibian species mentioned in Nawabi's (1965) paper, viz. *Rana ridibunda*, *Rana sternosignata*, and *Bufo viridis*, are currently identified as *Pelophylax terentievi* (Mezhzherin, 1992) *Chrysopaa sternosignata* (Murray, 1885) and a member of the *Bufotes viridis* (Laurenti, 1768) complex (see Wagner et al. 2016), most probably *B. pseudoraddei* (Mertens, 1971) (see Dufresnes et al. 2019). All these species are well known to be present in the Paghman area (Wagner et al. 2016).

Due to the German partnership project between the universities of Cologne and Bonn on the one side, and the University of Kabul on the other, Storai Nawabi had the chance to move to Bonn for the continuation of her studies where she worked with an entomological-parasitological topic (Kullmann & Nawabi 1971) and also with an arachnological-histological issue for her master thesis (Nawabi 1974).

The ZFMK received a valuable series of more than fifty *P.* (*A.*) *mustersi* specimens including also larval stages and egg sacs, collected by Clas M. Naumann (1939–2004), lepidopterist and founder of the Zoological Museum in Kabul (Naumann & Nogge 1973), from 1974 onwards husband of Storai Nawabi and later (from 1989) ZFMK's director (Böhme 2004; Häuser 2004; Schmitt 2005). Due to his efforts, a trial was made to collect money for the reconstruction of the Zoological Museum Kabul which was completely destroyed during the long Afghan wartime, the initiative being called "*Ein Stuhl für Kabul*" (= *A chair for Kabul*). However, this initiative failed, because of the still ongoing military confrontations which are likely to increase rather than to decrease in the next time. As this causes always also a great loss of biodiversity, the endemic, small-scaled distributed and thus highly threatened Afghan mountain salamander would thus make an ideal flagship species for the greatly neglected nature conservation in Afghanistan (Jablonski et al. 2021).

Acknowledgements. We thank Dr. Storai Naumann-Nawabi, Bonn, for providing us with some information. Mrs. Hamideh Fard, Museum Koenig Bonn, gave some linguistic advice. This study was supported by the Slovak Research and Development Agency under contract no. APVV-19-0076.

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APPENDIX I

Facsimile copy of the title page of the original article in Farsi.

SCIENCE, KABUL, SPECIAL EDITION (1965) p. 21-25

Wolfgang Böhme

S. NAWABI : Ein seltener Vertreter der Amphibia in Afghanistan:

یك ذو معیشتین نادر افغانستان :

Batrachyperus mustersi

از : ستوری نوابی

در جملهٔ حیوانات افغانستان ذو معشیتین یا امفیب کمتر شناخته شده اند . ذو معشیتین شا مل حیوانات فقاری بوده ودر بین گـروپ ماهی ها وخزندگـان جا گرفته حیات لاروی شان با ید در آب تکامل کنند طوریکه تنفس توسط برانشی ها صـورت میگیـرد . اما حیات متکا مل آن میتواند درخشکه با شد طوریکه سیستم تـنفس تغیر نموده : برا نشی ها تنفیص می کننـد وشش ها بمیان می آیند.

تـا جا ئیکه تاحال میدانیم زیاده تراز 400 نوع پرندگان درافغا نستان وتنها چهـا رنوع ذو معیشتین شناخته شده دلیل آن خشك بودن بسیاری از نقـاط مملکت بوده طوریکه در تا بستان گرم ودرز مستـان بالاتر از 1500m بسیار سرد می باشد ازجانب دیگـر دریا های موجوده بطورعموم دارای سطوح مختلفه ا ند چنا نچه در تا بستان قسمتاً خشك می گـردند ویا بعضی از آنها به قسم دریاچه ها آنقدر جریان سریع را دارا اند کـه درهمچو مناطق موجودیت این حیوانات انتظار نمیرود .

سه نوع از انواع شناخته شده مربوط به گروپ « Anura »(یا ذو معشیتین بی دم) هستند که دو نوع آن بقه ها بوده که نا م هایِ علمی - Rana ridibunda و Rana sternosignata رادارا می باشد .

نوع سوم آن کوربقه است که جنس آن Bufo یاد می شود نوع مربوط این جنس Bufo viridis ا ست که دارای ساحهٔ انتشار وسیع بوده درجوی ها بالای کوه ها ودرداخـل شهر مثلاً کـابل به تعداد فوق العاده زیاد ملاحظه شده میتواند.

تنهـا یك نوع « Urodela » (ذو معیشتن دمدار) کـه Batrachyperus mustersi نـامیده میشود شناخته شده که درسال ۱۹۳۹ کشف شده وبه حیث یك نوع جدید درسال ۱۹٤۰ توسط Smith تشریح گـردید

(Contribution to the herpetology of Afghanistan. annals and magazin cf natural History.ser ll.vol 5 382 . 384)

B. mustersi مربوط به فامیل Hynobiidae ا ست که دار 5 جنس می باشد

1- B. atrachyperus این جنس دارای دو نوع دیگر هم است B.pinchoni B. tibetanus که تنها در مناطق کوهستانی جنوب غربی چین شناخته شده .

2- Hynobius دارای ۹ نـوع است یکـی از آن Hynobius keyserlinglii شناخته انتشار آن از اورال Ural الی کمچنکا ، منگـولیـا ومنچوریا ودر اروپا در نیچی گورود Nishcegorod می باشد .

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First record of the lanternfly genus *Limois* Stål, 1863 in Vietnam with a new species, *L. sonlaensis* sp. nov. (Hemiptera: Fulgoromorpha: Fulgoridae)

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Abstract. The lanternfly genus *Limois* Stål, 1863 is recorded from Vietnam for the first time based on a new species, *L. sonlaensis* sp. nov. from Son La Province in North Vietnam. The new species is described and illustrations of the holotype and male genitalia and a distribution map, are provided. An updated identification key to the nine species of *Limois* is given.

Key words. Fulgoroidea, planthopper, Auchenorrhyncha, Tonkin, Indochina, China.

INTRODUCTION

The family Fulgoridae Latreille, 1807 contains about 774 species in 142 genera according to the FLOW database (Fulgoromorpha Lists On the Web – Bourgoin 2021), representing slightly less than 6 % of the species of Fulgoromorpha Evans, 1946 globally. In Vietnam, the family includes 37 species and the country is currently the most diverse in terms of lanternfly species as compared to other Indochinese countries such as Cambodia (17 species – Constant et al. 2016; Constant & Bartlett 2019), Laos (6 species – Bourgoin 2021), Thailand (16 species – Bourgoin 2021), and even China (32 species – Bourgoin 2021).

The genus *Limois* Stål, 1863 contains eight extant species and is distributed in the Oriental Region and the southeastern and far eastern parts of the Palaearctic Region: China (northeast China, Shanxi, Shaanxi, Hebei, Beijing, Gansu, Ningxia, Xizang, Hunan, Sichuan, Guangxi, Fujian), Taiwan, Japan, Korea, Far Eastern Russia, Bangladesh, northern India and Myanmar (Wang et al. 2020). It also contains two extinct species from China, and is the type-genus of the tribe Limoisini Lallemand, 1963 in the subfamily Aphaeninae Blanchard, 1847 (Wang et al. 2020; Bourgoin 2021).

The recent publication of a revision of the genus *Limois* by Wang and co-authors (Wang et al. 2020) attracted the attention of the second author to a specimen in the collection of the Vietnam National Museum of Nature, which was recognised as both an additional lanternfly genus for the fauna of Vietnam and a species new to science.

The aim of this paper is to describe the new species of *Limois*, *L. sonlaensis* sp. nov. as an addition to the biodiversity of Vietnam and to provide an updated identification key for the nine extant species of *Limois*.

MATERIALS AND METHODS

The male genitalia were extracted after boiling the distal portion of the abdomen several minutes in a 10% solution of potassium hydroxide (KOH) at about 100°C. The pygofer was separated from the remains of the abdomen and the aedeagus dissected with a needle blade for examination. The organs were then placed in glycerine for preservation in a tube attached to the pin of the specimen. The external morphological terminology follows O'Brien & Wilson (1985), the wing venation terminology follows Bourgoin et al. (2015) and for the male genitalia, Bourgoin & Huang (1990). The metatibiotarsal formula gives the number of spines on (side of metatibia) apex of metatibia/apex of first metatarsomere/apex of second metatarsomere.

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Abbreviations for measurements

The measurements were taken as in Constant (2004).

BF = maximum breadth of the frons
BTg = maximum breadth of the tegmen
BV = maximum breadth of the vertex
LF = length of the frons at median line
LTg = maximum length of the tegmen
LT = total length (apex of head to apex of tegmina)
LV = length of the vertex at median line

The photographs of the collection specimens were taken with a Canon 700D camera equipped with a Sigma 50 mm Macro lens; those of the terminalia, with a Leica EZ4W stereomicroscope with integrated camera, and in both cases, stacked with CombineZ software and optimized with Adobe Photoshop CS3. The distribution map was produced with SimpleMappr (Shorthouse 2010).

Institutional abbreviations

VNMN = Vietnam National Museum of Nature, Hanoi, Vietnam.
GTI = Global Taxonomy Initiative.

RESULTS

Order Hemiptera Linnaeus, 1758
Suborder Auchenorrhyncha Duméril, 1806
Infraorder Fulgoromorpha Evans, 1946
Superfamily Fulgoroidea Latreille, 1807
Family Fulgoridae Latreille, 1807
Subfamily Aphaeninae Blanchard, 1847
Tribe Limoisini Lallemand, 1963

Genus ***Limois*** Stål, 1863

Limois Stål, 1863: 230.
Type species: *L. westwoodii* (Hope, 1843).

Limois – Metcalf 1947: 170. — Lallemand 1963: 54. — Chou & Lu 1981: 221. — Chou et al. 1985a: 30. — Chou et al. 1985b: 108. — Nagai & Porion 1996: 22. — Wang et al. 2020: 36.

Species included [distribution]

Limois bifasciatus Ollenbach, 1928 [India, Uttarakhand State (Ollenbach, 1928)]
Limois chagyabensis Chou & Lu, 1981 [China: Xizang, Shaanxi, Sichuan (Wang et al., 2020)]
Limois emelianovi Oshanin, 1908 [China: Gansu, Dongbei (Wang et al. 2020); Russia (Oshanin 1908; Anufriev 2009); Korea (Doi 1932a, 1932b; Kwon & Huh 2001)].
Limois guangxiensis Chou & Wang, 1985 [China: Guangxi, Fujian (Wang et al. 2020)]
Limois hunanensis Chou & Wang, 1985 [China: Hunan (Wang et al. 2020)]
Limois kikuchii Kato, 1932 [China: northern China (Kato 1932, 1933), Shaanxi, Beijing (Liang 2005), Korea (Kato 1933; Metcalf 1947)]
Limois sonlaensis sp. nov. [Vietnam: Son La Province]
Limois sordida Wang, Xu, Constant & Qin, 2020 [China: Shanxi; Hebei, Beijing (Wang et al. 2020)]
Limois westwoodii (Hope, 1843) [Bangladesh (Hope 1843); China: Xizang; Myanmar (Wang et al. 2020)]

Identification key to the species of *Limois* Stål, 1863

1. Frons with three longitudinal carinae (Wang et al. 2020: figs 1E–F, 4C, 6E, 11D) 2
– Frons with two longitudinal carinae (Wang et al. 2020: figs 2E, 3B, 8D, 9D–F) 5
2. Pronotum with one dark irregular patch along the posterior margin on each lateral area (Wang et al., 2020: fig. 11B); base of hindwings yellow in male and red in female (Wang et al. 2020: fig. 11A, C) ... . ***L. emelianovi*** Oshanin, 1908
– Pronotum without one dark irregular patch along the posterior margin on each lateral area (Wang et al., 2020: figs 1D, 4B, 6D); base of hindwings concolorous in both sexes (Wang et al., 2020: figs 1A–B, 4A, D, 6A–B) 3
3. Pronotum brown (Wang et al., 2020: fig. 4B); genital styles distinctly elongate, subtriangular in lateral view (Wang et al., 2020: fig. 5A–B) .... ***L. kikuchii*** Kato, 1932
– Pronotum purplish red or dark brown (Wang et al. 2020: figs 1D, 6D); genital styles short, almost equilateral in lateral view (Wang et al. 2020: figs 1H, 7A, C) 4
4. Pronotum purplish red (Wang et al. 2020: fig. 1D); thorax sparsely covered with few dark spots (Wang et al., 2020: fig. 1D); irregular stripe in tegmina short and straight, not extending to anal angle (Wang et al., 2020: fig. 1A–C); apical half of endosomal processes exposed (Wang et al. 2020: figs 1K–L, 14C–D) ....***L. chagyabensis*** Chou & Lu, 1981
– Pronotum dark brown (Wang et al. 2020: fig. 6D); thorax densely covered with numerous dark spots (Wang et al., 2020: fig. 6D); irregular stripe in tegmina long, sinuately extending to anal angle (Wang et al., 2020: fig. 6A–C); apical ⅓ of endosomal processes exposed (Wang et al. 2020: figs 7D–E, 15C–D) ....***L. sordida*** Wang, Xu, Constant & Qin, 2020

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5. Thorax densely covered with numerous minute dark spots, disc of mesonotum without black marking (Fig. 1B; Wang et al. 2020: fig. 2D); tegmina submedially without strongly contrasting broad irregular band (Fig. 1A; Wang et al. 2020: fig. 2A) 6
– Thorax with minute dark spots sparse or absent, disc of mesonotum with black markings (Wang et al., 2020: figs 3A, 8B, 9B); tegmina submedially with contrasting broad irregular band (Wang et al. 2020: figs 3D, 8A, C, E, 9A, G) 7
6. Minute black spots density equal on disc of pro- and mesonotum (Wang et al., 2020: fig. 2D); postclypeus pale yellowish with minute darker spots (Wang et al., 2020: fig. 2E); dorsal angle of gonostyli rounded in lateral view (Wang et al. 2020: fig. 2G–H) .... ***L. guangxiensis*** Chou & Wang, 1985
– Minute black spots covering on disc of pronotum distinctly less dense than that on disc of mesonotum (Fig. 1B); postclypeus dark brown with irregular pale yellowish markings (Fig. 1C); dorsal angle of gonostyli forming a right angle in lateral view (Fig. 2A) ..... ***L. sonlaensis*** sp. nov.
7. Pronotum with 2 dark spots anteriorly, without one longitudinal broken black band on each side of median carina (Wang et al. 2020: fig. 3A) .... ***L. hunanensis*** Chou & Wang, 1985
– Pronotum without dark spots anteriorly, with one longitudinal broken black band on each side of median carina (Wang et al. 2020: figs 8B, 9B) 8
8. Tegmina with an oblique narrow fascia from apex to disc (Wang et al. 2020: fig. 13) .... ***L. bifasciatus*** Ollenbach, 1928
– Tegmina without an oblique narrow fascia from apex to disc (Wang et al. 2020: figs 8A, C, E, 9A, G) .... ***L. westwoodii*** (Hope, 1843)

Limois sonlaensis sp. nov.

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(Figs 1–4)

Material examined

Holotype

♂ (Figs 1–3). Vietnam, Son La Province; Thuận Châu District, Co Mạ, alt. 1,400 m; 21°21'11.5" N, 103°32'35.5" E; 7 Oct 2008; leg. Hoang Vu Tru; light trap; VNMN.

Diagnosis

The species can be separated from the other *Limois* species by the combination of the following characters:

1. Frons with two longitudinal carinae (Fig. 1C).
2. Pro- and mesonotum without large dark making on disc, only with minute black spots; spots distinctly less dense on pronotum than on mesonotum (Fig. 1B).
3. Postclypeus dark brown with irregular pale yellowish markings (Fig. 1C).
4. Tegmina with red suffusion on basal half of corium, the reddish area not reaching base and not extending to costal cell (Fig. 1A, D).
5. Posterior wigs with broad dark brown band along posterior margin and broad dark brown band separating basal orange-red area from transparent distal third (Fig. 1A, D).
6. Gonostyli with dorsal angle forming a right angle (Fig. 2A).

Differential diagnosis

The most similar species is *L. guangxiensis* Chou & Wang, 1985 from which *L. sonlaensis* sp. nov. can be separated, for example by the minute spots on disc of pronotum less densely distributed than on disc of mesonotum (spotting density similar on disc of pro- and mesonotum in *L. guangxiensis*) and by the pale yellowish ground colour of the postclypeus (postclypeus dark brown with irregular pale yellowish markings in *L. sonlaensis*).

Limois sonlaensis sp. nov. can be separated from the remaining other species of the genus by the absence of dark brown or black markings on the disc of the pro- and mesonotum. The remaining other species, except *L. westwoodii*, also lack the dark brown band separating the orange-red basal area from the transparent distal area of the posterior wings.

Etymology

The species epithet refers to Son La Province in North Vietnam, where the type specimen was collected.

Description

Measurements and ratios. LT: ♂ (n = 1): 20.6 mm. LTg/BTg = 2.6; LV/BV = 0.5; LF/BF = 1.03.

Head. Vertex excavate, with all margins carinate; about two times broader than long; weakly transversely wrinkled; with a broadly U-shaped carina along median $^2/_4$ of posterior margin; pale yellow with irregular brown markings in middle and at posterolateral angles (Fig. 1B, E). Posterior face of head pale yellowish with two longitudinal brown markings near middle (Fig. 1B, E). Frons about as broad basally as long in mid-line (excluding cephalic process); slightly convex in lateral view; broadest with margins rounded near fronto-clypeal suture, then moderately tapering dorsad with lateral margins broadly incurved; portion above fronto-clypeal suture slightly excavate, then median portion of disc elevated; elevation tapering dorsad and gradually turning into two side-by-side carinae extending nearly to apex of cephalic process; frons mostly dark brown mottled with pale yellow and rather densely covered in minute black points (Fig. 1B–C, H). Cephalic process directed posterodorsally, tapering towards apex; in lateral view, anterior margin rounded and posterior margin straight,

oblique; anterior face with lateral margins foliate laterally near base and two parallel median carinae stopping before a small lamina; small lamina followed by excavate apex of process; posterior face of process flattened, elongate with sides parallel and lateral margins carinate, and dorsal margin angularly pointed dorsad; pale yellowish slightly variagated with brown and with irregular minute reddish brown points, and with carinae of anterior face dark brown (Fig. 1B–C, E–F, H). Genae pale yellowish with few brown markings (Fig. 1E, H). Eyes large, about half as wide as vertex in dorsal view, strongly rounded and protruding laterally (Fig. 1B–C). Ocelli well-developed, under compound eyes (Fig. 1H). Antennae rather short, subcylindrical, black-brown (Fig. 1E, H). Clypeus convex, elongate, subtriangular, carinate medially with carina stronger on anteclypeus; lateral margins carinate on basal ⅔ of postclypeus; base narrower than frons; brown with anteclypeus darker and transverse irregular pale yellowish markings; some minute black points on postclypeus along lateral and median carinae (Fig. 1C–D). Labium brown, very elongate and narrow, surpassing apex of abdomen, with last segment much shorter than penultimate (Fig. 1D).

Thorax. Pronotum wider than long with lateral angles acutely pointed lateroventrally in dorsal view; anterior margin strongly bisinuate, roundly emarginated behind eyes, slightly emarginate behind vertex; posterior margin more or less straight, abruptly oblique near lateral angle; weak median carina on anterior half of disc with a deep impressed point at each side; disc transversely wrinkled posterior to impressed points; anterolateral margin strongly carinate; paranotal lobes with strong carina parallel to anterolateral margin on dorsal ⅓ and ventral margin carinate; ventral ⅔ of paranotal lobes coarsely punctured; pale yellowish dorsally with some minute dark brown dots and one bigger black point behind eye; paranotal lobes with area between carinae dark brown with large pale yellowish markings dorsally; ventral ⅔ of paranotal lobes dark brown variegated with yellowish (Fig. 1B–C, E–F, H). Mesonotum subtriangular with very weakly marked median and peridiscal carinae; median carina stopped before scutellum; peridiscal carinae incurved on anterior ¼; scutellum slightly elevated, following a shallow depression; ground colour pale yellowish; disc densely covered in irregular small black dots; lateral fields beyond peridiscal carinae smooth with some black-brown markings including a curved marking anteriorly (Fig. 1B, E, H). Tegulae pale yellowish with irregular minute black points on ventral ⅔ (Fig. 1B, E, H).

Tegmina. (Fig. 1A, D, G) Elongate, slightly more than 2.5 × as long as broad, with a small round lobe posterior to clavus (damaged on right wing of holotype); apical angle rounded; apical margin strongly oblique; costal cell pale yellowish brown with irregular rather large black-brown markings; clavus pale yellowish with irregular dark brown markings, markings larger on distal ⅔; basal ½ of corium opaque, pale yellowish with large black-brown markings and a large reddish zone on disc, not reaching base and more visible ventrally (Fig. 1D); distal half transparent with large markings and veins, dark brown (Fig. 1A, D, G). Venation dense and reticulate, with numerous secondary veins and cross-veinlets; Pc+CP extending slightly beyond nodal line; ScP+R(+MA) very short; RP(+MA) merged with MP at basal $^2/_5$ of clavus; PCu and A1 fused at about ¾ of clavus length (Fig. 1A).

Hind wings. (Fig. 1A, D) Elongate, roundly pointed apically, with posterior margin roundly indentate at claval fold. Basal half bright orange turning to bright red distally; distal half transparent with broad dark brown, C-shaped band between bright red and transparent areas; broad dark brown band along posterior margin; vein CuA dark brown marked by an elongate dark brown marking progressively widening towards the posterior and abruptly stopped at first fork of CuA; three dark brown makings along vein A1 in orange area.

Legs. (Fig. 1A, D) Elongate and slender. Dark brown; femora with irregular pale yellow markings more or less arranged in rings; tibiae with 2 well-defined pale yellowish rings, the more distal one broader. Metatibiotarsal formula: (5–6) 7 / 8–9 / 6.

Abdomen. Tergites orange with broad dark brown band along basal margin (Fig. 1A, D); ventral face black-brown (Fig. 1D).

Terminalia. *Male*. Pygofer (*Py*) with ventral margin sinuate in lateral view; posterior margin in lateral view slightly convex, emarginate on ventral $^1/_6$ (Fig. 2A); in dorsal view deeply, roundly emarginate posteriorly (Fig. 2C, F); posterior margin slightly roundly projecting posterad in ventral view (Fig. 2D). Gonostyli (*G*) subtriangular in lateral view, with dorsal angle right and posterior margin rounded (Fig. 2A), in ventral view gonostyli connected basally (Fig. 2D), lateral hook (*lhg*) slender, directed posteroventrally, then curved ventrally towards apex (Fig. 2A–B, D). Phallobase sclerotized in basal $^1/_6$, sheath cylindrical, phallobasal conjunctival processes sclerotized over entire length, about five times as long as sheath, apical ¼ curved dorsad and terminally membranous and inflated, phallus with a dorsal and a ventral pair of elongate membranous processes (Fig. 3A–B, D–G). Connective rod-like (Fig. 3A). Tectiductus rather large, in lateral view elongate, in dorsal view broad, subsquarish, distinctly concave ventrally (Fig. 3A–E, G). Anal tube (*An*) massive, in lateral view reaching level of apex of gonostyli, ventral margin nearly straight, apical margin obliquely, roundly truncate (Fig. 2A), in dorsal view, widening from base to apex, 1.09 × broader near apex than long in median line, 1.34 × longer in maximum length than wide at maximum width, apical margin roundly emarginate in dorsal view (Fig. 2C); anal column (*ac*) elongate, surpassing posterior margin of anal tube (Fig. 2A, C).

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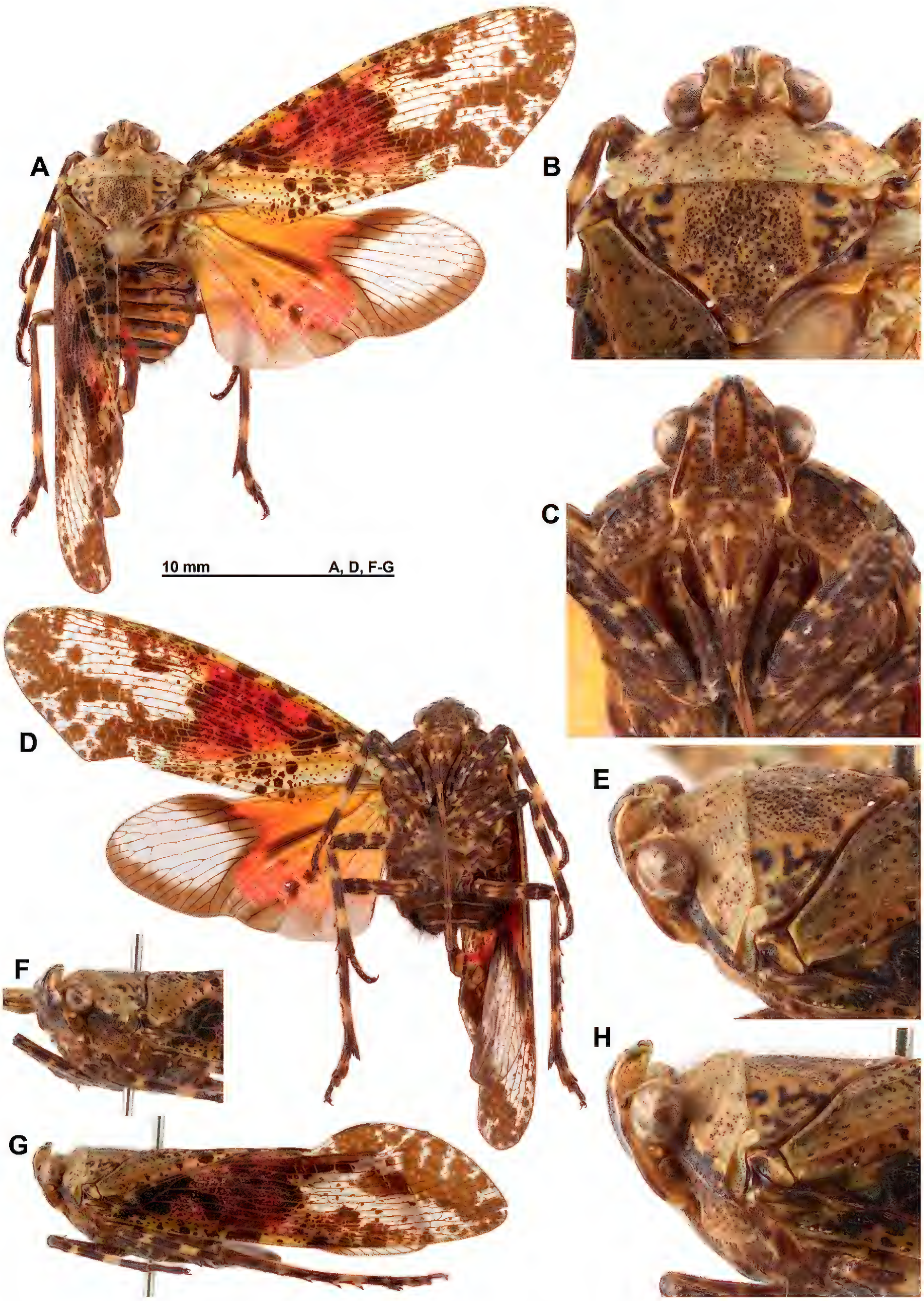


Fig. 1. *Limois sonlaensis* sp. nov., ♂, holotype (VNMN). **A**. Habitus, dorsal view. **B**. Head and thorax, dorsal view. **C**. Head and thorax, perpendicular view of frons. **D**. Habitus, ventral view. **E**. Head and thorax, laterodorsal view. **F**. Head and thorax, anterolateral view. **G**. Habitus, lateral view. **H**. Head and thorax, lateral view.

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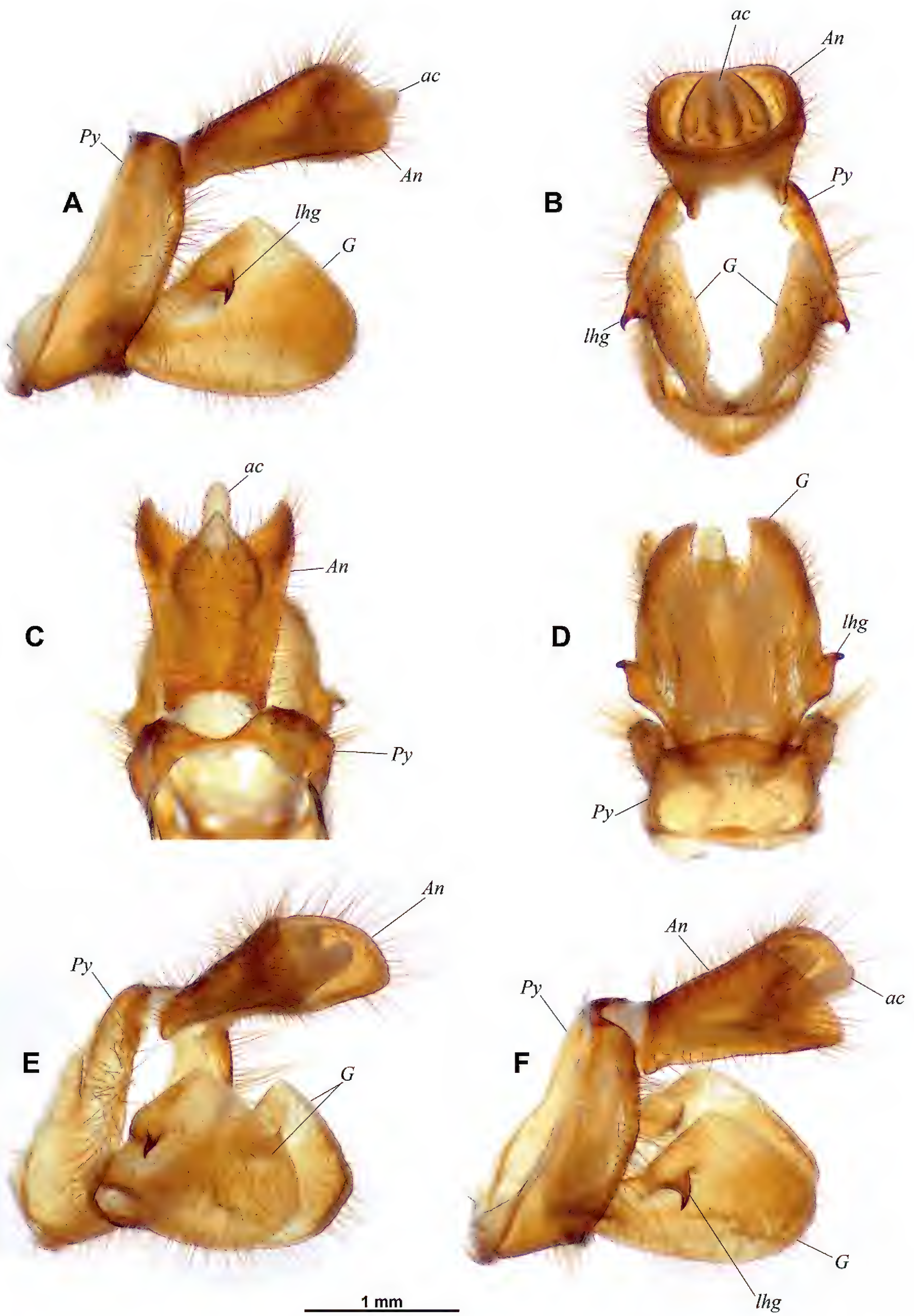


Fig. 2. *Limois sonlaensis* sp. nov., ♂, holotype (VNMN), terminalia: anal tube, pygofer and gonostyli. **A**. Left lateral view. **B**. Caudal view. **C**. Dorsal view. **D**. Ventral view. **E**. Posterolateral view. **F**. Laterodorsal view. Abbreviations: *ac* = anal column; *An* = anal tube; *G* = gonostylus; *lhg* = lateral hook of gonostylus; *Py* = pygofer.

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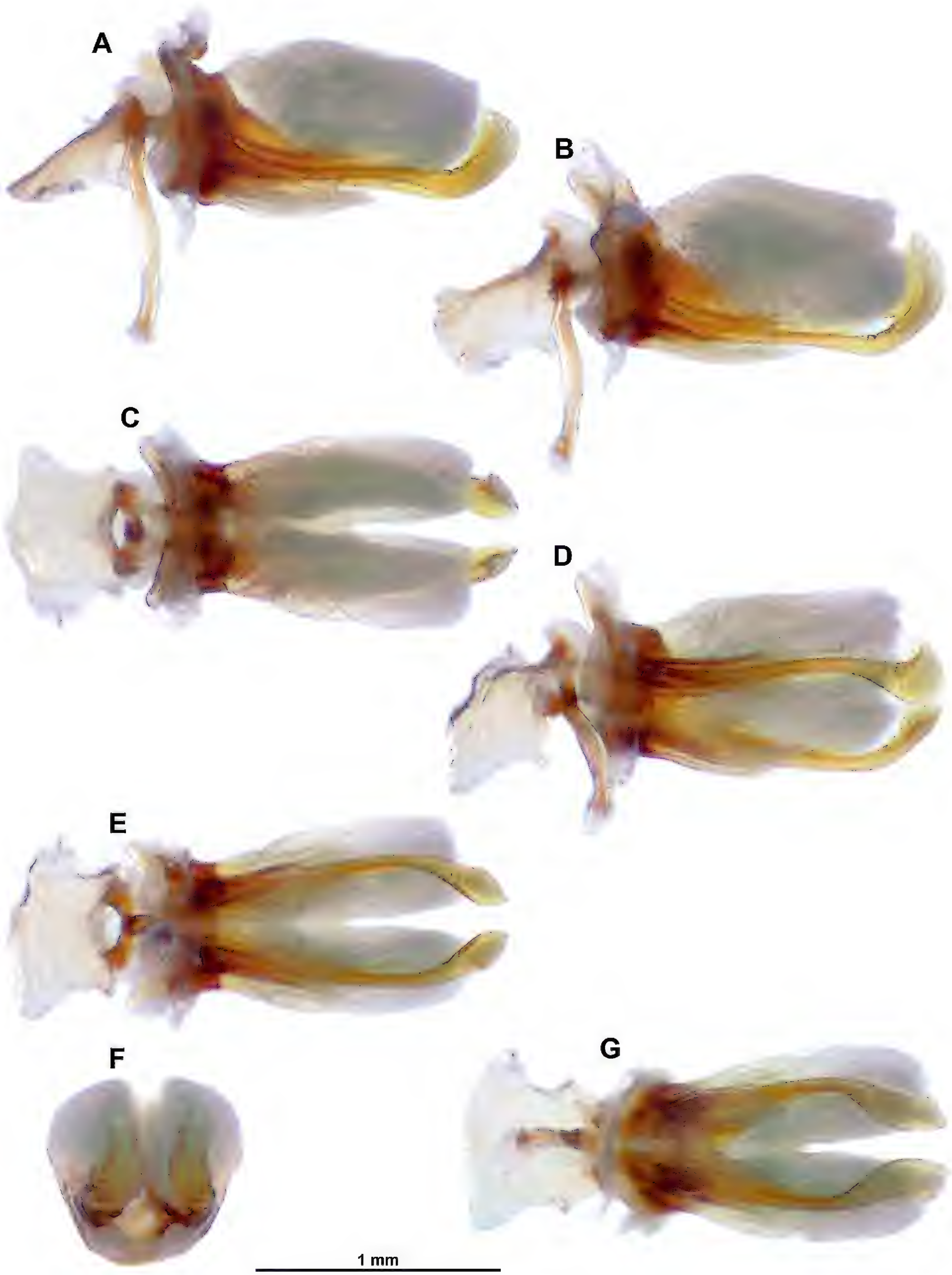


Fig. 3. *Limois sonlaensis* sp. nov., ♂, holotype (VNMN), terminalia: aedeagus and connective. **A**. Lateral view. **B**. Laterodorsal view. **C**. Dorsal view. **D**. Lateroventral view. **E**. Ventral view. **F**. Caudal view. **G**. Posteroventral view.

Note
Limois sonlaensis sp. nov. is the only species of the genus in which RP(+MA) is merging with MP on tegmina. Both tegmina of the specimen show this character. However, as only one male is available, this character needs to be confirmed from additional material in the future, and might represent a good diagnostic character to recognize this species.

Biology
The specimen was collected at a light trap in secondary mountain tropical evergreen forest, at 1,400 m in altitude (Fig. 4).

Distribution
Vietnam, Son La Province (Fig. 4).

DISCUSSION

The genus *Limois* now contains nine species, seven of which being present in China. The genus is also found in northern India, Myanmar, Bangladesh, Far Eastern Russia and South Korea (Wang et al. 2020), and it is here recorded from Vietnam for the first time. Despite the recent collecting effort, especially in China, very little is known about the natural history of these species, and host plants remain completely undocumented so far. Specimens are quite scarce in the collections, even if it happens that they get collected from light traps. The fact that they seem to prefer mountainous habitats leads to the hypothesis that probably more species exist which will be discovered in the future.

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Fig. 4. *Limois sonlaensis* sp. nov., distribution map.

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A new species of *Cryptopacha* Prozorov & Zolotuhin, 2012 (Lasiocampidae: Lasiocampinae) from West Africa

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Abstract. A new species of *Cryptopacha* is described from West Africa: *C. smithi* sp. n. The habitus and genitalia are illustrated and a comparison made with its closest congener, *C. porphyria* (Holland, 1893). These two taxa are separated by the Dahomey Gap and their distribution is discussed in relation to this barrier to speciation.

Key words. Lappet moths, Dahomey Gap, biogeography, taxonomy.

INTRODUCTION

The lappet moth genus *Cryptopacha* Prozorov & Zolotuhin, 2012 was erected by Prozorov & Zolotuhin (2012) to include a single species, *Metanastria porphyria* Holland, 1893, described from Gabon and thought to be widely distributed in the lowland forests of Central and West Africa. *Cryptopacha porphyria* (Holland, 1893) is an unmistakable species with a characteristic forewing pattern of white and purplish-brown bands on a red-brown background. As part of recent DNA barcoding efforts by the African Natural History Research Trust (ANHRT), individuals from Central and West Africa were sampled and the results suggested two, genetically divergent populations existing either side of the Dahomey Gap. Morphological studies of genitalia corroborated the molecular results and a new species from West Africa is described herein.

MATERIAL AND METHODS

Primary label data have been transcribed verbatim with "//" denoting a different label and "/" denoting a line break. Genitalia were dissected, stained with Eosin red and mounted in Euparal on microscope slides applying standard methods of preparation (Lafontaine & Mikkola 1987). Photos of adults were taken using a Nikon D90 SLR camera equipped with a Nikkor AF Micro 60 mm lens. Genitalia were photographed using a Canon EOS 700D camera mounted on a Wild M3Z stereo microscope. All images were edited in Adobe Photoshop. Genitalia terminology follows Prozorov & Zolotuhin (2012).

DNA barcodes were obtained by removing tarsal segments from adult specimens before being submitted to the Canadian Centre for DNA Barcoding (CCDB, Biodiversity Institute of Ontario, University of Guelph). Sequences were obtained using Single Molecule Real-Time sequencing through the Sequel (PacBio) pipeline at CCDB (Hebert et al. 2018). The resulting sequences were aligned using MUSCLE in MEGA ver. X (Kumar et al. 2018) and genetic distances were calculated using Kimura's two-parameter model (Kimura 1980).

RESULTS

Taxonomy

Family Lasiocampidae Harris, 1841
Subfamily Lasiocampinae Harris, 1841
Genus *Cryptopacha* Prozorov & Zolotuhin, 2012

Cryptopacha smithi sp. n.
urn:lsid:zoobank.org:act:F06AA4E5-515A-412B-B33A-CC8B40B58618
Figs 1–5

Diagnosis

Cryptopacha smithi is very similar in appearance to *C. porphyria* but in the latter, the forewing markings are more heavily contrasting, the silvery-white bands (particularly the one beyond the submarginal band) are wider and better defined and placed at slightly more of an obtuse angle to the costal margin (Fig. 6). In the male genitalia of *C. porphyria*, the tegumen is wider, the socii

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are longer and the valves are more robust and shorter (the valve-socii ratio is almost 1:1). The phallus is larger and the pointed apical section longer in *C. porphyria* and the digitiform projections of sternite VIII are more robust, shorter and with greater serrations apically (Figs 7–9). As these two species are distributed allopatrically, there is unlikely to be any confusion in specimens with good provenance.

Etymology

It is with great pleasure that this new species is dedicated to Richard Smith, the director of the African Natural History Research Trust, for his continued support of and dedication to African entomology and in particular Lepidoptera systematics.

Material examined

Holotype
WEST AFRICA – Sierra Leone • ♂; "SIERRA LEONE 120m / Tiwai Island, Moa River / N07°33′00″, W11°21′09″ / 17–22.vi.2016 Light Trap / leg. Takano, Miles & Goff / ANHRT:2017.18 // ANHRTUK / 00029947 // Gen. slide No. / LG 5618 m# / prep. by Gy. M. Laszlo"; ANHRT.

Paratypes (38 ♂♂ 1 ♀)
WEST AFRICA – Guinea • 5 ♂♂; Massadou campsite, Forêt Classée de Ziama; 08°20′36.25″ N, 09°26′14.70″ W; alt. 541 m; 15–17.iii.2019; Sz. Sáfián and S. Koivogui leg.; Light Trap; ANHRT – **Ivory Coast** • 18 ♂♂; Tai National Park; 05°50′00″ N, 07°20′32.0″ W; alt. 174 m; 25.iii–17.iv.2017; A. Aristophanous, M. Aristophanous, M. Geiser and P. Moretto leg.; MV Light Trap; ANHRT • 6 ♂♂, 1 ♀; Tai National Park; 05°49′59.8″ N, 07°20′32″ W; alt. 174 m; 5–10.vii.2015; M. Aristophanous, P. Moretto and E. Ruzzier leg.; Light Trap; ANHRT – **Liberia** • 1 ♂; East Nimba Nature Reserve, Cellcom Road; 07°31′2.18″ N, 08°31′1.90″ W; alt. 1300 m; 31.iii–04.iv.2017; Sz. Sáfián and G. Simonics leg.; Light Trap; ANHRT • 3 ♂♂; Foya Proposed Protected Area; 07°56′36″ N, 10°16′36″ W; alt. 530 m; 10–19.xi.2017; M. Aristophanous, Sz. Sáfián, G. Simonics and L. Smith leg.; MV Light Trap; ANHRT • 2 ♂♂; Welezu camp, Wonegizi Nature Reserve; 08°04′57.11″ N, 09°34′47.86″ W; alt. 561 m; 19–27.iii.2019; Sz. Sáfián and S. Koivogui leg.; Light Trap (Blended Bulb); ANHRT • 1 ♂; Krahn-Bassa Reserve, Juboe River; 05°39′04″ N, 08°39′04″ W; alt. 140 m; 14–20.i.2018; M. Geiser, Sz. Sáfián and G. Simonics leg.; Light Trap (Blended Bulb); ANHRT – **Sierra Leone** • 1 ♂; same collection data as for holotype; ANHRT • 1 ♂; Kambama village on the banks of the Moa River; 07°33′29″ N, 11°21′51″ W; alt. 110 m; 22.vi.2016; H. Takano, W. Miles and R. Goff leg.; Light Trap; ANHRT.

Description

External morphology of adults (Figs 1–2)

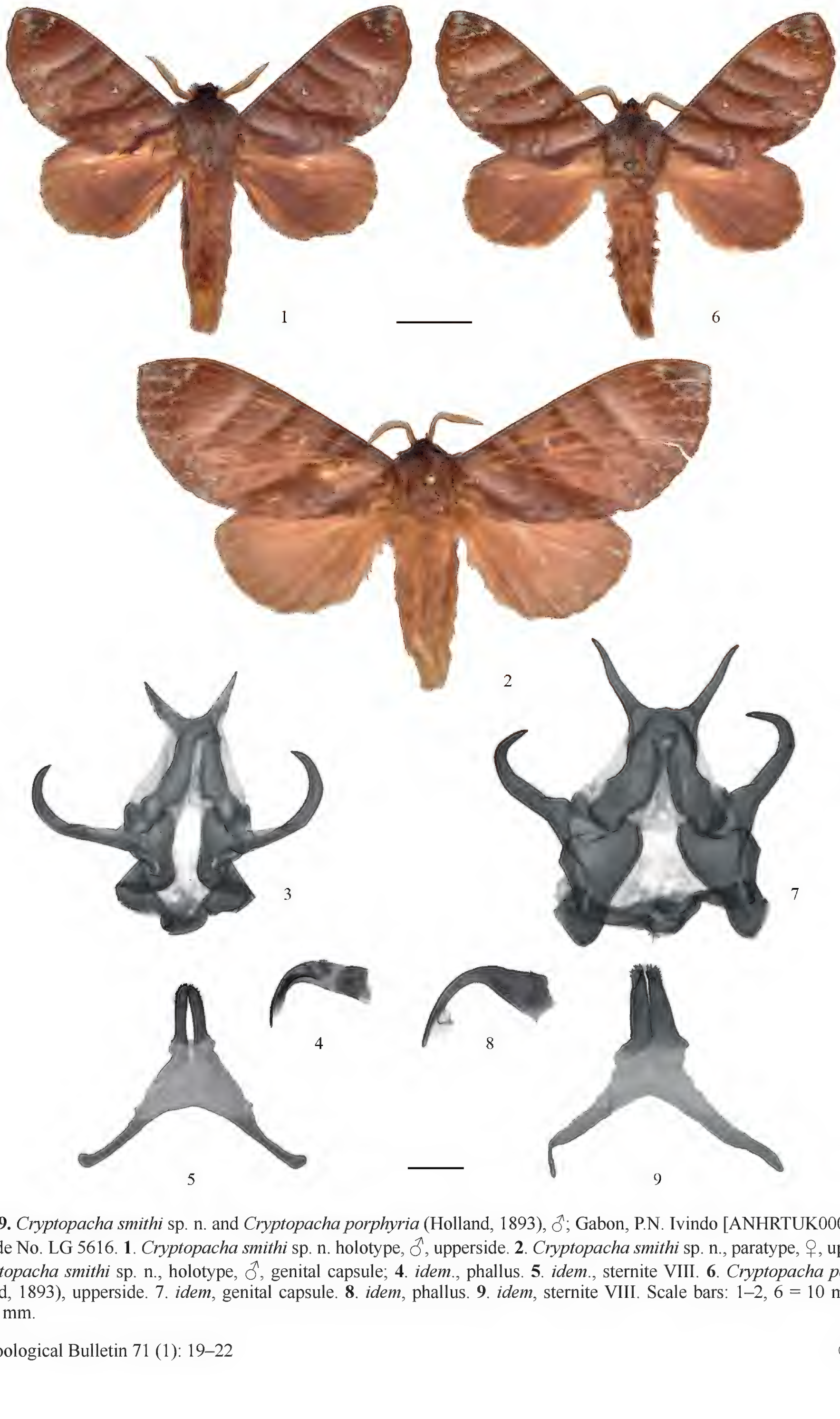
Forewing length
Holotype: 26 mm; range: 24–26 mm; female: 36 mm.

Upperside
Ground colour of head, thorax and forewings purplish-brown mixed with densely scattered grey and white scales. Head with a low longitudinal crest. Antennae brown, bipectinate; rami lighter in colour. Patagia with slightly greyer scales posteriorly. Tegulae with transverse patch of white scales medially. Abdomen hirsute, covered in long red-brown hairs. Forewing rounded, outer margin gently sinuate. Basal two-thirds (up to the submarginal line) with silvery-mauve diffuse patches atop the ground colour separated by dark brown bands and silvery-white bands on their outer edge; basal band, straight; double antemedial bands which kink inwards towards dorsal margin at vein CuA2, posterior section slightly sinuate; transverse band filling the space between veins A1+A2 and CuA2, bisecting the antemedial bands just below CuA2 and extending to the outer margin. Discal spot white, well-developed. Postmedial and submarginal bands slightly arcuate anteriorly kinking sharply towards dorsal margin at vein M3, posterior sections beyond sinuate. Subterminal band zigzagged with dark brown and white markings at corners, originating at apical marking. Apical marking triangular, graphite-grey with silvery markings on inner and outer edges. Hindwing outer margin slightly sinuate; same ground colour as forewing, becoming paler towards the costa; anal fold pale. Fringe greyish-brown, darkened at the veins.

Underside
Ground colour of head, thorax, legs purplish-brown; labial palps brown. Forewing underside similar in colour to upperside but slightly paler; basal and antemedian bands absent; postmedial band well developed, submarginal band less so, both bands converging towards dorsal margin. Broad diffuse greyish-white band beyond submarginal band, well-defined towards costal margin. Yellowish scales along veins most clearly defined in the subterminal area. Hindwing ground colour similar to forewing but overlaid with creamy scales except for tornal region and postmedial, submarginal and subterminal bands. Terminal band indicated by yellowish-white lunules. Yellowish scales along veins most clearly defined in the subterminal area reaching as far as postmedial line.

Female
Ground colour of body and wing pattern on both upperside and underside similar to male but slightly paler.

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Figs 1–9. *Cryptopacha smithi* sp. n. and *Cryptopacha porphyria* (Holland, 1893), ♂; Gabon, P.N. Ivindo [ANHRTUK00039000]; gen. slide No. LG 5616. **1**. *Cryptopacha smithi* sp. n. holotype, ♂, upperside. **2**. *Cryptopacha smithi* sp. n., paratype, ♀, upperside. **3**. *Cryptopacha smithi* sp. n., holotype, ♂, genital capsule; **4**. *idem*., phallus. **5**. *idem*., sternite VIII. **6**. *Cryptopacha porphyria* (Holland, 1893), upperside. 7. *idem*, genital capsule. **8**. *idem*, phallus. **9**. *idem*, sternite VIII. Scale bars: 1–2, 6 = 10 mm; 3–5, 7–9 = 1 mm.

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Male genitalia (Figs 3–5)
Uncus and gnathos absent; tegumen bell-shaped, apically with a pair of robust conical socii, each basally as wide as the width of tegumen. Tuba analis membranous. Valve fully sclerotised, tubular, sickle-shaped, curved caudad, two and a half times longer than the socii. Vinculum sclerotised, curved dorsad. Saccus band-shaped. Anellus membranous. Phallus short, strongly curved medially, basally dilated, apically pointed. Sternite VIII with a pair of heavily-sclerotised digitiform posterior projections with serrations apically. Apodemes long, narrow and rounded at extremities.

DNA divergences
The new species has been assigned the COI-5P cluster number BOLD:AAZ9255. Interspecific pairwise distances between the new species and *C. porphyria* ranged from 6.2–6.4%.

Distribution
Cryptopacha smithi is a species of the Upper Guinean Forests distributed from Sierra Leone to Ivory Coast.

DISCUSSION

Cryptopacha smithi and its sister species *C. porphyria* are distributed allopatrically on either side of the Dahomey Gap, a 200 km wide belt of open vegetation separating the Upper and Lower Guinean Forest blocks. This region was once covered by closed-canopy forest during the mid-Holocene but rapid aridification following the Holocene Climatic Pejoration resulted in the domination of savannas in the Dahomey Gap (Demenou et al. 2018). Numerous studies have shown that the Dahomey Gap can be a significant barrier to gene flow for those species restricted to forest habitats (e.g., Dongmo et al. 2019), and further genetic and morphological studies of Lasiocampidae, as well as other Lepidopteran groups will undoubtedly reveal many more sibling taxa separated by this barrier.

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Research article

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Assessing the distribution of the Andalusian endemic *Berberomeloe payoyo* Sánchez-Vialas et al., 2020 (Coleoptera: Meloidae), with comments on its ecology

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Abstract. Thanks to recent molecular studies, it was revealed that one of the biggest European beetles, the red-stripped oil beetle *Berberomeloe majalis* (Linnaeus, 1758) (Coleoptera: Meloidae) comprised a complex of nine different species. To improve the knowledge of this threatened group, chorology of the newly described microendemic *B. payoyo* Sánchez-Vialas et al., 2020 is updated in pursuit of a better knowledge and future adequate conservation strategies. 252 field sampling events were performed between 2012-2021. 668 specimens were studied. In the framework of the study, two citizen science projects were carried out. The first detailed distribution map and notes about the species' biology are provided.

Keywords. Biodiversity, blister beetles, entomology, Iberian endemism, insect conservation.

INTRODUCTION

Berberomeloe Bologna, 1989 is an endemic genus from the Ibero-Maghrebian region and includes some of the biggest European, which can reach a body length of up to 7 cm (Bologna 1989; García-París 1998; Cortés-Fossati 2018a). This genus has remained unchanged for thirty years including two species, the red-stripped oil beetle *Berberomeloe majalis* (L., 1758) and *B. insignis* (Charpentier, 1818). Recent molecular studies focused on *B. majalis* revealed a complex of nine morphologically and phylogenetically distinct species (Sánchez-Vialas et al. 2020). Among these nine species the new south-western Iberian microendemic *B. payoyo* Sánchez-Vialas et al., 2020 (Fig. 1) was described, being distributed in Cádiz province, Málaga, and Granada provinces (Andalusia, Spain) (Sánchez-Vialas et al. 2020). Currently, there are hardly any data and only scarce studies available about the natural history and biology of *B. payoyo* (Cortés-Fossati 2018a, b; Cortés-Fossati & Cervera 2018; Sánchez-Vialas et al. 2020). However, this information is crucial to design appropriate and specific conservation strategies. In this case – even though no Spanish oil beetle species is protected under any legal framework – it was important to consider that the only catalogued species within the genus, *Berberomeloe insignis*, was classified as vulnerable (VU) in the Andalusian and Spanish Red Book of Invertebrates (Barea-Azcón et al. 2008; Verdú et al. 2011). The species is affected by several impacts, mainly related with environment transformation (García-París & Ruiz 2008, 2011). These threats are observed for *B. payoyo* in some areas (Cortés-Fossati 2018a, b; Cortés-Fossati and Cervera 2018, sub *B. majalis*) but the information we have on the species is outdated and scarce , including its distribution range. Up-to-date distribution information and a georeferenced map are key tools in conservation (D'Amen et al. 2013; Della Rocca et al. 2020), especially in the cases of complexes of closely related species. This could reveal potential cases of sympatry or allopatry and clarify the geographic distribution ranges of each of the species of the *B. majalis* complex, improving knowledge and contributing to decrease the Wallacean shortfall, i.e., the lack of knowledge about the geographical distribution of species (Lomolino 2004; Cardoso et al. 2011). Therefore, the aim of this study is to provide a better understanding of the chorology and ecology of the Iberian *B. payoyo*.

MATERIAL AND METHODS

The dataset has been generated by 1) own sampling campaigns; 2) citizen science programs, and 3) available literature, from the oldest reported observation to the most recent, covering the period 1921–2021.

1) Field sampling campaigns were carried out from 2012 to 2021, from January to August to safely cover the time interval in which imagos of the species are present in the field (from March to July in southern Spain: Bologna, 1989). Specimens were identified according to Sán-

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chez-Vialas et al. (2020). The species presents distinctive morphological and biogeographical characteristics that allowed all individuals to be identified (Sánchez-Vialas et al. 2020). The first is that the taxonomic identity of the species is very clear in most of the area it occupies, being restricted to the south-west of the Iberian Peninsula. Secondly, *B. payoyo* presents among other characteristics (for more details, see identification key and description in Sánchez-Vialas et al. 2020) narrow, coloured post-tergal bands (Fig. 1A), poorly impressed punctures on the head (Fig. 1B), and anterior angles of the pronotum are not expanded (Fig. 1C). These features differentiate *B. payoyo* from the other species of the complex present in eastern Andalusia (*B. indalo* Sánchez-Vialas et al., 2020 and *B. tenebrosus* Sánchez-Vialas et al., 2020). Specimens that could not be reliably determined based on their morphology, as happened in four cases, were excluded from the study. 252 samplings events were carried out in 86 different sampling points. 668 specimens were studied in the field in 29 different locations. All populations/records were georeferenced. The number of individuals, colouration of post-tergal bands, and biological/behavioural observations were also noted.

2) Additional observations were received by the author by mail, or were uploaded by citizens to two different Citizen Science Programs in which the author was administrator ("Proyecto Biodiversidad de Andalucía", hosted in collaboration with iNaturalist.org and the "Proyecto Meloidata", hosted in collaboration with Observation.org), and were also included in the database. Likewise, the veteran Spanish nature conservation association Biodiversidad Virtual (biodiversidadvirtual.org) provided their observations concerning the species from its internal database. Only those observations were considered, in which the specimens could be reliably identified from photographs that had georeferencing and date.

3) The only seven publications that provided location data were considered for this study (Bologna 1989; García-París 1998; Pérez-Moreno et al. 2003; García-París et al. 2003; Percino-Daniel et al. 2013; Cortés-Fossati 2018, Sánchez-Vialas et al. 2020). In most cases, due to the age of these works, there was not a very high spatial precision in them, so the locations have subsequently been referenced estimating their position with the data provided in these works. On the other hand, in works before 2020, only locations have been considered in which, according to Sánchez-Vialas et al. (2020), the taxonomic identity of the species *B. payoyo* is clear, that is, the province of Cádiz, and certain areas of Malaga and Granada.

The resulting distribution map was generated with software QGIS ver. 3.16.1-Hannover (GIS Development Team 2020) using a EPGS:4326-WGS 84 coordinate system and the layers "Terrestrial 10×10 km grid" from Ministerio para la Transición Ecológica y el Reto Demográfico (miteco.gob.es) and "Líneas límite provinciales" from the Instituto Geográfico Nacional (centrodedescargas.cnig.es). In a complementary way, notes about ecology and conservation of the populations studied were registered.

RESULTS & DISCUSSION

An updated chorology of the species is provided based on 154 different locations (Appendix: Table S1), allowing to establish a well-represented distribution map, since a large part of its potential distribution area has been covered (Fig. 2). This total number has been formed by data from fieldwork, citizen science and literature. During field sampling, the species was present in 29 locations of 86 sampled, belonging to 14 different municipal districts. Citizen science programs functioned satisfactorily, obtaining 84 valid observations from this source, belonging to 84 different locations. It could be noted that, especially in rural areas, villagers generally have a good knowledge about genus *Berberomeloe*, a phenomenon already observed for the Cádiz region (Cortés-Fossati 2018a, Cortés-Fossati & Cervera 2018) and for the Iberian Peninsula (García-París et al. 2016) probably due to the ethnopharmacological uses that the hemolymph of these animals has historically developed (Percino-Daniel et al. 2012). This fact may be the main reason why this program has given reliable results. Finally, the literature review provided 41 locations, only eight of them georeferenced.

According to previous literature (Bologna 1989; García-París 1998; Cortés-Fossati 2018a, b) *Berberomeloe payoyo* is a diurnal xerophilous species, inhabiting diverse Mediterranean habitats (see Sánchez-Vialas *et al*. 2020), being also distributed in suburban landscapes with degraded vegetation (Cortés-Fossati 2018a, b). Nevertheless, the species seemed to have preference on open areas, steppe lands and meadows with presence of bare soil patches and not very dense, pioneer vegetation where females oviposit (Cortés-Fossati 2018; Fig. 3). Here, its presence can be massive (up to 200 individuals registered in 0.27 ha in a single day). During evening time individuals have been observed on several occasions to leave the foraging area to hide under leaf litter or grass in areas of denser vegetation where they spend the night (pers. obs.). Adults are present in the field from the end of February to mid-July, being very rare outside this period (e.g., one single adult record in January cited by Sánchez-Vialas et al. 2020). Highest abundance occurred between end of March and end of May (Fig. 4). Earliest oviposition was observed at the end of March (03/21/2017 in Puerto Real). Offspring hatched between 20 and 26 days later (three replicates carried out in March 2014, March 2017, and May 2017 in the laboratory in translucent 10L terrariums in sand substrate with natural conditions of light, humidity, and temperature). Characteristic of first instar

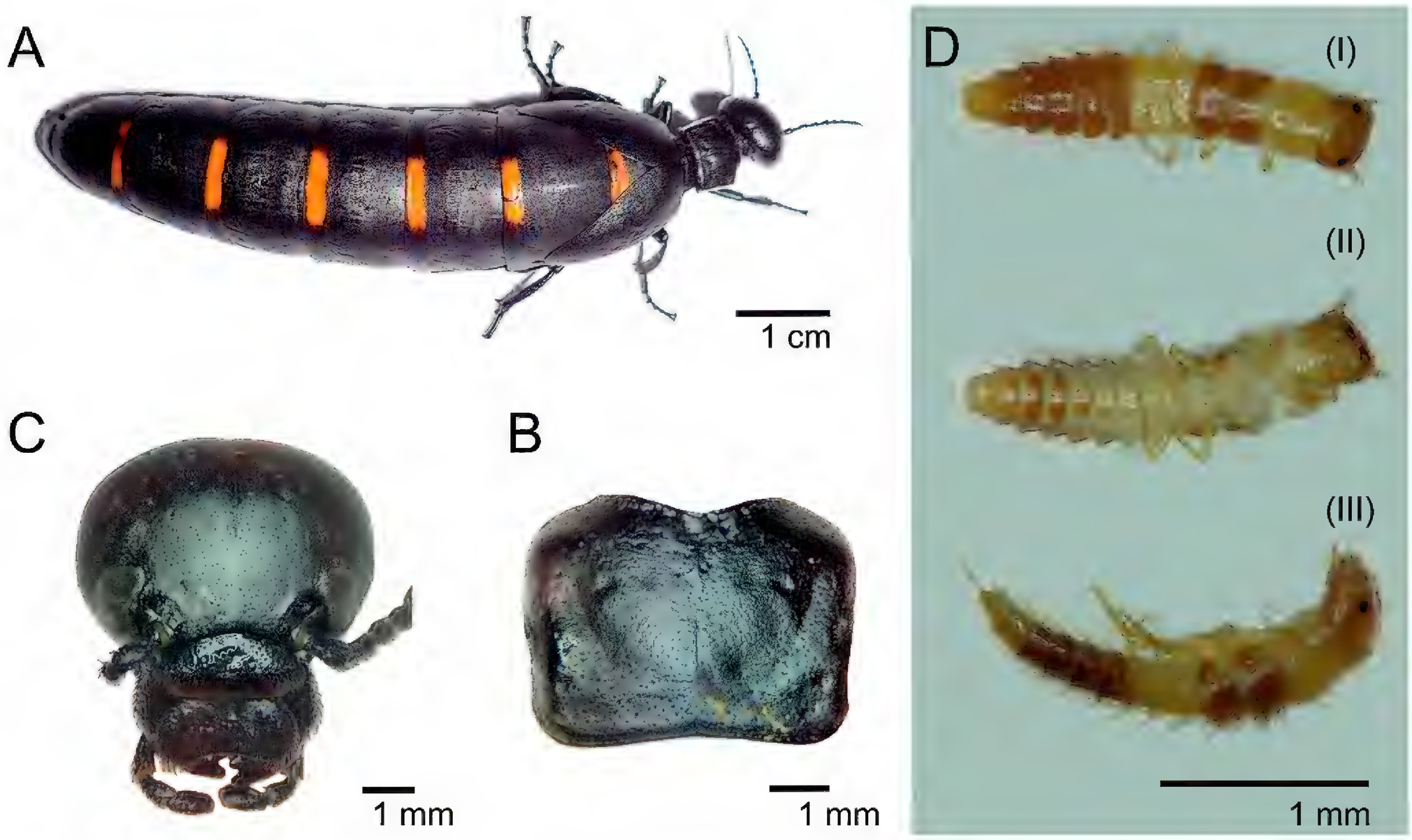


Fig. 1. *Berberomeloe payoyo* Sánchez-Vialas et al., 2020. **A**. Imago from Puerto Real, Cádiz. Dorsal view. **B**. Pronotum. **C.** Head front view, with characteristic punctures. **D**. First instar larva in dorsal (I), ventral (II) and lateral view (III). Instars were damaged during collection, lacking their terminal long chaetae, partially visible in III.

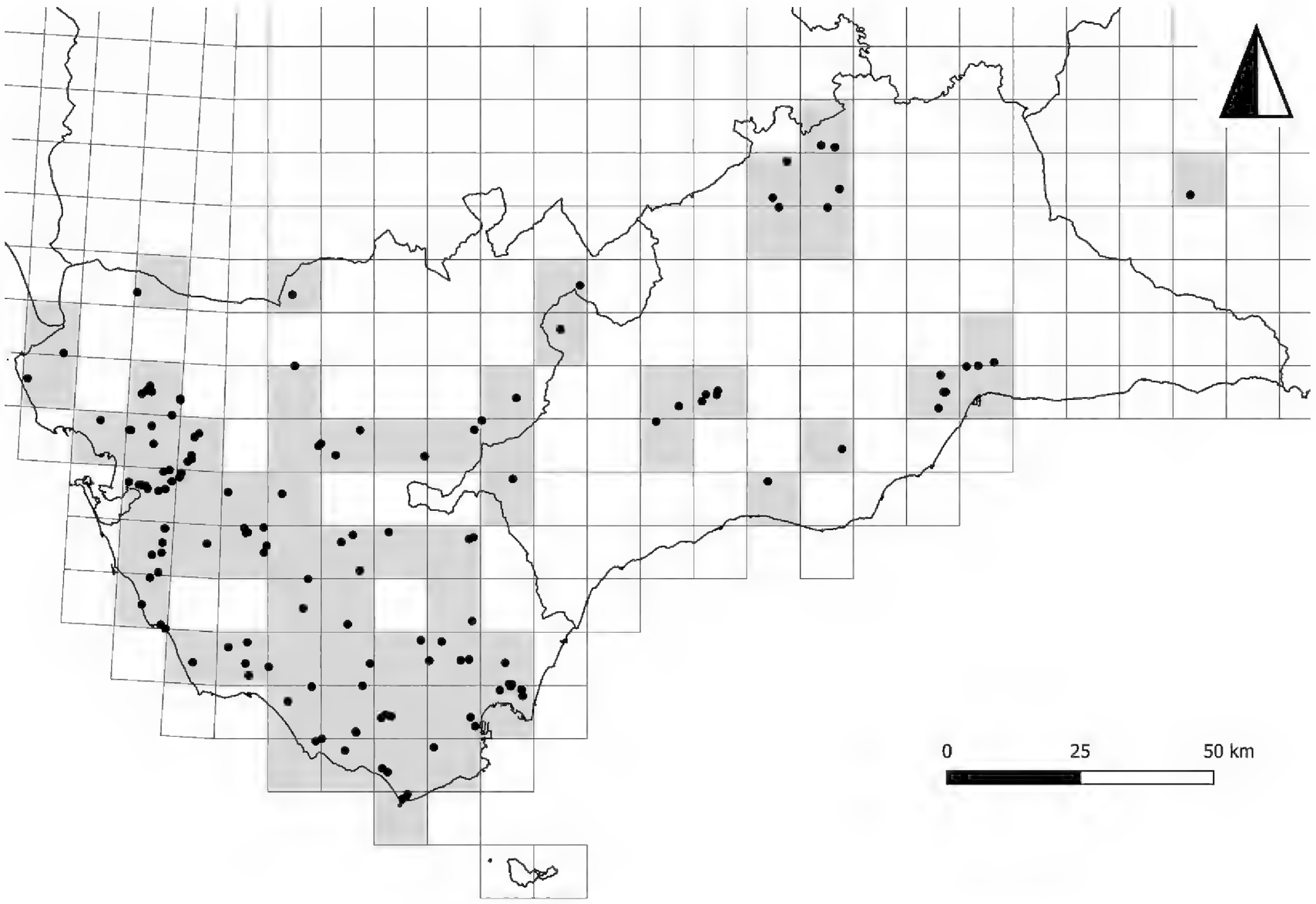


Fig. 2. Distribution of *Berberomeloe payoyo* composed with data from sampling campaigns, citizen science records and literature records.

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Fig. 3. Typical environment where the species seems to have preference, consisting of open areas with no dense vegetation (Medina Sidonia, Cádiz).

larva (Fig. 1D) corresponds to the description made by Bologna (1989) for the larvae from the *B. majalis* complex, not observing appreciable differences.

Based on the findings, it is also possible to conclude the absence of this species in the coastal strip and marshy ecosystems, at least, in tidal influence areas and beach sand substrate (after 113 samplings and studying all the data provided by third parties, absent in the tidal zone and marshes of Algeciras, Barbate, Cádiz, Chiclana de la Frontera, Chipiona, Conil de la Frontera, Puerto Real, Puerto de Santa María, Sanlúcar de Barrameda, Tarifa).

As expected, no sympatry cases with other *Berberomeloe* species were detected in Cádiz, but a genetic study of the possible contact areas is necessary, in this case, the limit zone of distribution in the east, since there may be cases of introgressive hybridization that do not allow the individuals to be correctly identified morphologically, and even, hybrid populations may be present.

Intraspecific variation of the populations was detected, in terms of the post-tergal band colouration, which can range from light orange to reddish orange and even vermilion red, the orange-coloured form being probably the most common in Cádiz province (Appendix: Table S2,- Fig. S2). No populations with mixed specimens of different band colours have been detected. No completely black morphotype specimens were observed.

According to personal observation, imagos feed on leaves of different pioneer and herbaceous plants species as well as young shoots. However, they seem to show preference on flower petals of certain plants species such as those of the genus *Echium* L. (Boraginaceae). Throughout this study, also repeated feeding on diverse Asteraceae (highlighting *Carduus* L., *Galactites* Moench, and *Pallenis* Cass), and on *Oxalis pes-caprae* L. (Oxalidaceae) has been observed. *Berberomeloe payoyo* has also been observed feeding on *Erodium* L'Hér. ex Aiton (Geraniaceae), *Plantago* L. (Plantaginaceae) and *Lysimachia* (L.) U. Manns and Anderb. (Myrsinaceae).

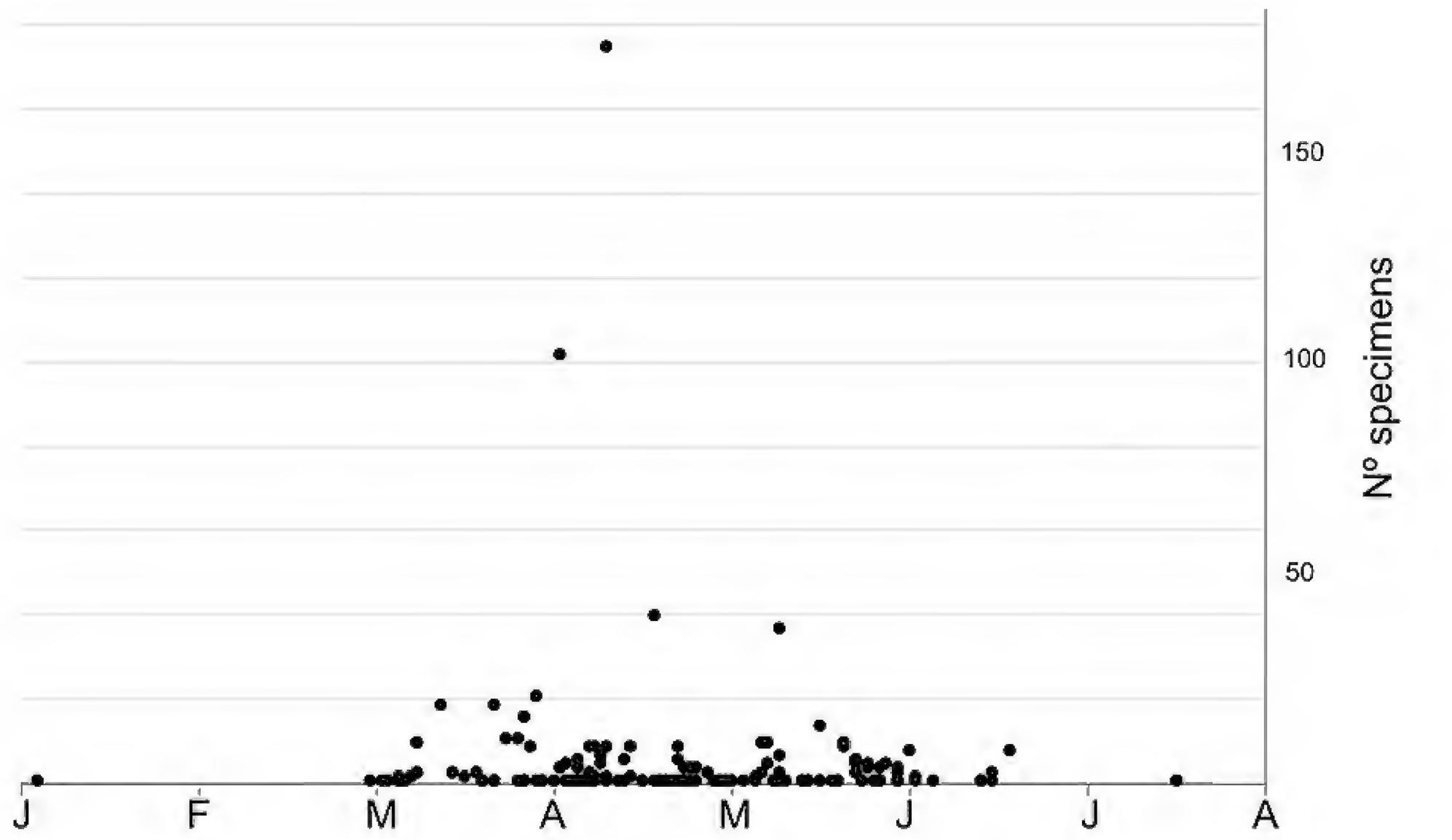


Fig. 4. Phenology of imago of *Berberomeloe payoyo*, built from the database generated for the study. Literature or citizen science data that lacked the number of observed individuals by date have been plotted as n = 1.

No studies have been conducted on the conservation status of the species. However, data collected during this work suggest that populations near cities undergo a negative anthropogenic pressure. The ecosystems of the Cadiz and Málaga provinces are highly transformed and fragmented, except for some well-preserved natural cores such as Grazalema, Los Alcornocales or Sierra de las Nieves Natural Parks. Agriculture and an aggressive urbanistic process occupies most of the area, increasingly taking ground in its development over the years. In this way, in Cádiz it is very frequent to observe populations of *B. payoyo* located on croplands and peri-urban regions with a clear degree of deterioration (Cortés-Fossati 2018a). Totally or quasi-isolated populations due to human infrastructures have been observed (e.g., diverse populations in Chiclana de la Frontera, Puerto Real, Jerez de la Frontera, Sanlúcar de Barrameda) since the species has a very low dispersal rate and a low capacity to colonize new areas (García-Paris 1998; Sánchez-Vialas et al. 2020). Use of steppe lands or zones dominated by colonizing pioneer r-strategist plant species as uncontrolled waste dumps, urban pressure, and the agricultural fields as well as the use of chemicals are probably affecting populations, threats already proposed as impacts for other Meloidae (García-París & Ruíz 2008a, b, 2011; Ruíz & García-París 2008a, b). In these zones, populations seem degraded and with lower population densities. Also, road kills have been observed very frequently, a phenomenon also observed for the Madrilenian *Berberomeloe* populations (García-París et al. 2006; pers. obs.). Even possible local extinction of some populations has been observed during this work. In 2012, an expansion to a mega commercial area was carried out in Jerez de la Frontera (Area Norte and Area Sur, see Appendix: Table S1). The species has no longer been observed there since 2016, also not appearing again in the adjoining crop fields. Moreover, a population located in a cropland in Torre del Puerco (see Appendix: Table S1), completely disappeared in 2017 after changes in land use in the area. However, geographical situation of this population suggests it could be derived from another nucleus, located on a semi-natural shrubland in front of the sampling point, found behind several linear structures that fragment the area (two walkways and a road). So, if transformation will not continue, there could be a possibility that the beetle will return to the area. Finally, during 2017, in Puerto Real: Parque Entrevías (see Appendix: Table S1), the species apparently disappeared after diverse human interventions, e. g., illegal deposit of debris and the installation of a pipeline that flooded the study area. As of 2018, a large decline in number of individuals was observed. After that season, no specimen has been observed in the area. However, there are no data on dynamic populations that allow calculating possible regressions or the real status of the species, so it would be necessary to carry out studies focused on conservation ecology.

CONCLUSIONS

Berberomeloe payoyo Sánchez-Vialas et al., 2020 is a microendemic restricted to the south-west of the Iberian Peninsula that is well represented throughout its area of distribution. Information collected provides an update on the distribution of *B. payoyo* and some ecological notes that improve the knowledge about the species. The information regarding its ecology and biological cycle seems to fit very well to what was already stated by Bologna (1989) when the genus was described (Bologna 1989; García-París 1998; García-París et al. 2003; Cortés-Fossati 2018). At least, peri-urban populations seem to suffer from negative human impacts, e.g., habitat fragmentation and change in land use. Future works on the conservation ecology of the species are needed.

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Ethical & legal aspects. This study was framed under the legal regulations and laws for the collection and ethical treatment of animals and has been endorsed by Andalusian government.

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APPENDIX I

(*electronic supplement, available at www.zoologicalbulletin.de*)

Table S1. Location dataset composed by data from field work (F), citizen science programs (CS) and Literature (L: authors, year). Dates indicated in intervals pertaining to the field campaings represent a sustained work in the period between January and August of those years.

Table S2. List of specimens studied in the field in which the color of the banding was noted. The observations are divided between two classes, Orange (O) which is represented on the map with orange dots and Red (Red) represented on the map with red dots. Only those individuals from the sampling campaigns were included in the study as the colors could not be standardized from photographs provided by third parties.

Fig. S2. Mapping of specimens studied on field divided by colouration in the post-tergal banded pattern. The observations are divided between with orange dots (populations with orange bands and black dots (populations with red bands) represented on the map with red dots. Only those individuals from the sampling campaigns and Cortés-Fossati, 2018 were included in the study as the colors could not be standardized from photographs provided by third parties. According to citizen science data, which have not been taken into account in the plot because it cannot be corroborated – since despite having testimonies and photos the colors have not been normalized with a scale – the red individuals would be confined to the northern part of the province and the southern part of the same Strait Zone), leaving the central strip of the province dominated by populations of orange coloration, thus being probably the most widespread coloration.

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Table S1. Location dataset composed by data from field work (F), citizen science programs (CS) and Literature (L: authors, year). Dates indicated in intervals pertaining to the field campaings represent a sustained work in the period between January and August of those years.

Source	Province	Locality (Municipal D.)	Location	X, Y	MASL	Date obs.
F	CADIZ	Alcalá de los Gazules	El Algibe	36.44570, -5.74695	48	2016-2017
F	CADIZ	Algeciras	Sierra de la Plata	36.11251, -5.77617	388	2018-2019
F	CADIZ	Arcos de la Frontera	Arroyo del Salado	36.74120, -5.85514	50	22.05.16
F	CADIZ	Barbate	Sierra del Retín	36.17378, -5.84883	285	2018-2019
F	CADIZ	Chiclana de la Frontera	East peri-urban area	36.41881, -6.12198	15	09.04.17
F	CADIZ	Chiclana de la Frontera	South-West peri-urban area	36.41452, -6.14204	6	09.04.17
F	CADIZ	Chiclana de la Frontera	Torre del Puerco	36.33004, -6.16010	21	2016-2017
F	CADIZ	Conil de la Frontera	Fuente del Gallo	36.29054, -6.10900	13	01.05.13
F	CADIZ	Jerez de la Frontera	Area Sur Shopping centre	36.69224, -6.15621	44	2013-2019
F	CADIZ	Jerez de la Frontera	Arroyo Canaleja, South stretch	36.67779, -6.09269	14	2015-2017
F	CADIZ	Jerez de la Frontera	Arroyo Canaleja, East stretch	36.67972, -6.09339	12	2015-2017
F	CADIZ	Jerez de la Frontera	Arroyo de la Loba	36.69169, -6.16478	11	2016-2017
F	CADIZ	Jerez de la Frontera	Campiña del Área Norte	36.68620, -6.17414	26	2016-2017
F	CADIZ	Jerez de la Frontera	Campiña del Área Sur	36.69996, -6.15733	35	2013-2019
F	CADIZ	Jerez de la Frontera	Cartuja Santa María Defensión	36.65135, -6.10955	5	09.05.14
F	CADIZ	Jerez de la Frontera	El Pedroso	36.52443, -5.98691	110	2016-2017
F	CADIZ	Jerez de la Frontera	Laguna de Medina	36.61580, -6.06087	36	17.03.17
F	CADIZ	Jerez de la Frontera	Zoological Park parkings	36.69006, -6.15332	62	2014-2019
F	CADIZ	Línea la Concepción	Sierra Carbonera	36.19398, -5.35895	220	2018-2019
F	CADIZ	Los Barrios	La Teja, Alcornocales Nat. Park	36.28370, -5.57462	263	07.04.17
F	CADIZ	Medina Sidonia	Arroyo del Azúcar	36.46683, -5.91008	114	01.06.17
F	CADIZ	Medina Sidonia	Arroyo Golondrina/Croplands	36.42423, -5.90806	53	2017
F	CADIZ	Medina Sidonia	Colada de la Espartera	36.43629, -6.02801	29	24.05.17
F	CADIZ	Medina Sidonia	Croplands near Saltillo	36.45661, -5.94742	92	2016-2017
F	CADIZ	Medina Sidonia	Croplands near Saltillo (2)	36.46475, -5.95086	96	2016-2018
F	CADIZ	Paterna de Rivera	Arroyo Pozomedina/ croplands	36.52451, -5.87369	106	19.05.17
F	CADIZ	Puerto Real	Peri-urban area	36.53215, -6.17407	21	2017

F	CADIZ	Trebujena	South croplands	36.85740, -6.19088	14	2016-2017
F	CADIZ	Vejer de Frontera	Arroyo Montecote/ Croplands	36.26264, -5.97657	20	01.06.17
CS	CADIZ	Alcalá de los Gazules	Embalse de Barbate	36.39830, -5.70650	37	14.06.18
CS	CADIZ	Alcalá de los Gazules	Near Mirador de los Tallones	36.46497, -5.64809	138	19.04.19
CS	CADIZ	Algeciras	Urban zone	36.14075, -5.45623	23	03.04.17
CS	CADIZ	Barbate	Near Arroyo Mondragón	36.21585, -5.93205	2	29.04.17
CS	CADIZ	Benalup-Casas Viejas	Embalse del Celemín	36.30733, -5.72880	45	NA
CS	CADIZ	Castellar de la Frontera	Puerto Juan Alonso/Guadarranque	NA	NA	NA
CS	CADIZ	Castellar de la Frontera	Sierra Montecoche	36.28233, -5.53112	273	NA
CS	CADIZ	Chiclana de la Frontera	Cañada Picapollos	36.45983, -6.11653	35	26.05.15
CS	CADIZ	Chiclana de la Frontera	El Marquesado	36.46005, -6.11715	33	22.04.18
CS	CADIZ	Chiclana de la Frontera	Pago de Humo	36.40732 -6.08526	13	12.04.21
CS	CADIZ	Chiclana de la Frontera	Pinar del Hierro	36.38523, -6.12780	19	18.04.21
CS	CADIZ	Chipiona	Urbanización Costa Ballena	36.70557, -6.41539	10	23.05.18
CS	CADIZ	Espera	Cañada Jerez-Utrera	36.86150, -5.86470	113	19.05.18
CS	CADIZ	Jerez de la Frontera	Near Arroyo de la Gallina	36.59469, -5.57690	212	26.05.18
CS	CADIZ	Jerez de la Frontera	Laguna de Medina	36.62210, -6.05190	44	29.05.17
CS	CADIZ	Jerez de la Frontera	Laguna del Tejón	36.57407, -6.07349	60	29.05.17
CS	CADIZ	Jerez de la Frontera	Las Canteras y el Tejón	36.57845, -6.06554	60	29.05.17
CS	CADIZ	Jerez de la Frontera	Las Canteras el Tejón Croplands	36.58476, -6.06608	68	29.05.17
CS	CADIZ	Jimena de la Frontera	Arroyo de los Hoyones	36.45684, -5.47904	171	29.05.17
CS	CADIZ	Jimena de la Frontera	Río Hozgarganta	36.45979, -5.47008	406	26.05.15
CS	CADIZ	Los Barrios	Embalse de Almodóvar	36.15347, -5.63273	121	16.05.15
CS	CADIZ	Los Barrios	Embalse Zanona	36.24179, -5.67973	181	NA
CS	CADIZ	Los Barrios	Near Garganta del Cabrero	36.25150, -5.48990	283	12.06.13
CS	CADIZ	Los Barrios	Near Garaganta Curtidora	36.25330, -5.47260	291	30.03.17
CS	CADIZ	Los Barrios	Sendero Palancar	36.24939, -5.55560	89	NA
CS	CADIZ	Manzanete	Manzanete	NA	NA	NA
CS	CADIZ	Medina Sidonia	Croplands	36.43572, -5.90323	69	03.04.20
CS	CADIZ	Puerto Santa María	El Martillo Industrial area	36.62448, -6.19817	14	20.04.13
CS	CADIZ	Puerto de Santa María	Peri-urban croplands	NA	NA	NA
CS	CADIZ	Puerto de Santa María	Rancho Linares	NA	NA	NA

CS	CADIZ	Puerto de Santa María	Sierra San Cristóbal	36.63250, -6.15120	115	07.03.21
CS	CADIZ	Puerto Real	Arroyo del Castaño	36.54700,-6.08969	67	29.05.17
CS	CADIZ	Puerto Real	Arroyo de la Zarza	NA	NA	NA
CS	CADIZ	Puerto Real	Arroyo de las Yeguas	NA	NA	NA
CS	CADIZ	Puerto Real	Camino Torrealta	36.52619, -6.15571	22	16.04.21
CS	CADIZ	Puerto Real	Camino Los Barreros	36.53163, -6.16760	24	22.03.10
CS	CADIZ	Puerto Real	East peri-urban forested area	36.55845,-6.11097	22	NA
CS	CADIZ	Puerto Real	Forested-shrubby area	36.55426,-6.08621	86	29.05.17
CS	CADIZ	Puerto Real	La Chacona	36.52646, -6.11869	56	30.03.18
CS	CADIZ	Puerto Real	Peri-urban cropland	36.53978,-6.10563	42	29.05.17
CS	CADIZ	San José del Valle	Arroyo del Palmetín	36.63580, -5.71410	111	23.04.16
CS	CADIZ	San José del Valle	El Acebuchal	36.59244, -5.76379	205	NA
CS	CADIZ	San José del Valle	Peri-uban ring	36.60721, -5.80027	137	14.05.17
CS	CADIZ	San Roque	Estación Ambiental Madrevieja	36.20270, -5.40670	6	25.04.15
CS	CADIZ	San Roque	Monte bajo	NA	NA	NA
CS	CADIZ	San Roque	Peri-urban area	36.20974, -5.38457	111	07.04.09
CS	CADIZ	San Roque	Pinar del Rey	NA	NA	27.03.85
CS	CADIZ	San Roque	Sierra Carbonera	NA	NA	01.04.82
CS	CADIZ	Tarifa	Arroyo del Molino	36.20403, -5.69441	83	NA
CS	CADIZ	Tarifa	Arroyo Cagancha	36.15347, -5.63273	118	16.05.15
CS	CADIZ	Tarifa	Camino de la Pista	36.06480, -5.64840	68	08.05.21
CS	CADIZ	Tarifa	Campiña Tarifeña	NA	NA	NA
CS	CADIZ	Tarifa	Cerro de Bartolo	36.09313, -5.72697	368	05.05.08
CS	CADIZ	Tarifa	Near Cortijo Aguilón	36.12480, -5.70490	75	01.05.17
CS	CADIZ	Tarifa	Embalse de Almodóvar	36.15057, -5.65305	90	10.05.18
CS	CADIZ	Tarifa	Pico Luna	36.10292, -5.54157	781	20.05.17
CS	CADIZ	Tarifa	Río de la Jara	36.05870, -5.63700	5	23.04.19
CS	CADIZ	Tarifa	Sierra la Plata	36.10799, -5.78828	348	29.04.18
CS	CADIZ	Torre Alháquime	Abandoned cropland	36.89050, -5.25950	604	01.05.17
CS	CADIZ	Ubrique	Los Alcornocales Natural Park	36.641672, -5.473934	NA	28.04.12
CS	CADIZ	Ubrique	South peri-uban area	NA	NA	01.05.17
CS	CADIZ	Vejer de la Frontera	Near Arroyo Donadillo	36.27180, -5.93740	8	26.05.18

CS	CADIZ	Vejer de la Frontera	Near el Ciruelo	36.23510, -6.04980	30	13.05.18
CS	CADIZ	Vejer de la Frontera	Near Río Barbate	36.23580, -5.93970	3	23.05.12
CS	CADIZ	Villaluenga del Rosario	Peri-urban area	36.69740, -5.38767	870	05.05.08
L: Bologna, 1989	CADIZ	NA	Bay of Cádiz Area, see Fig. 10	NA	NA	NA
L: Bologna, 1989	CADIZ	NA	La Janda Area, see Fig. 10	NA	NA	NA
L: Bologna, 1989	CADIZ	NA	Bay of Algeciras, see Fig. 10	NA	NA	NA
L: García-París, 1998	CADIZ	NA	N Bay of Cádiz Area, see Fig. 1	NA	NA	NA
L: García-París, 1998	CADIZ	NA	S Bay of Cádiz Area, see Fig. 1	NA	NA	NA
L: García-París, 1998	CADIZ	NA	Bay of Algeciras, see Fig. 1	NA	NA	NA
L: García-París *et al.*, 2003	CADIZ	Algeciras	NA	NA	NA	21.04.21
L: García-París *et al.*, 2003	CADIZ	Algeciras	NA	NA	NA	23.04.21
L: García-París *et al.*, 2003	CADIZ	Algeciras	NA	NA	NA	24.04.21
L: García-París *et al.*, 2003	CADIZ	Alcalá de los Gazules	NA	NA	NA	NA
L: García-París *et al.*, 2003	CADIZ	Jerez de la Frontera	NA	NA	NA	16.03.85
L: García-París *et al.*, 2003	CADIZ	Jerez de la Frontera	Laguna de Medina	NA	NA	27.03.83
L: García-París *et al.*, 2003	CADIZ	San Roque	NA	NA	NA	00/05/1973
L: García-París *et al.*, 2003	CADIZ	Tarifa	NA	NA	NA	00/04/1971
L: Pérez-Moreno *et al.*, 2003	CADIZ	Ronda	Sierra de las Nieves	NA	NA	10.04.87
L: Pérez-Moreno *et al.*, 2003	CADIZ	San Roque	NA	NA	NA	00/05/1987
L: Pérez-Moreno *et al.*, 2004	CADIZ	San Roque	NA	NA	NA	00/05/1971
L: Pérez-Moreno *et al.*, 2003	CADIZ	Tarifa	NA	NA	NA	20.03.89
L: Percino-Daniel *et al.*, 2013	CADIZ	Benalup-Casas Viejas	Benalup de Sidonia	NA	NA	NA
L: Percino-Daniel *et al.*, 2013	CADIZ	Chiclana de la Frontera	NA	NA	NA	NA
L: Percino-Daniel *et al.*, 2013	CADIZ	Vejer or Algodonales?	La Muela	NA	NA	NA
L: Percino-Daniel *et al.*, 2013	CADIZ	NA	3km S Alcalá de los Gazules	NA	NA	NA
L: Cortés-Fossati, 2018	CADIZ	Medina Sidonia	Arroyo del Saltillo	36.45757, -5.94340	37	2016-2018
L: Cortés-Fossati, 2018	CADIZ	Puerto Real	East croplands	36.53127, -6.16051	37	2016-2018
L: Cortés-Fossati, 2018	CADIZ	Puerto Real	Parque de Entrevías	36.53636, -6.19546	366	2014-2021
L: Cortés-Fossati, 2018	CADIZ	Sanlúcar de Barrameda	Las Dunas industrial area	36.75019, -6.34113	39	04.06.17
L: Sánchez-Vialas *et al.*, 2020	CADIZ	Conil de la Frontera	Fuente del Gallo	36.29691, -6.11925	28	13.04.13
L: Sánchez-Vialas *et al.*, 2020	CADIZ	Facinas (Barbate)	Facinas	36.12633, -5.70572	NA	19.06.16

L: Sánchez-Vialas *et al*., 2020	CADIZ	Manzanete	Sierra del Retín	NA	NA	04.01.18
L: Sánchez-Vialas *et al*., 2020	CADIZ	Manzanete	Sierra del Retín	36.20000, -5.80000	NA	24.03.11
L: Sánchez-Vialas *et al*., 2020	CADIZ	Paterna de Rivera	NA	NA	NA	21.05.17
L: Sánchez-Vialas *et al*., 2020	CADIZ	NA	2 km S Benalup Sidonia	NA	NA	19.04.01
L: Sánchez-Vialas *et al*., 2020	CADIZ	NA	7 km SW Benalup Sidonia	NA	NA	19.04.01
L: Sánchez-Vialas *et al*., 2020	CADIZ	NA	4km NE San José del Valle	NA	NA	19.04.01
L: Sánchez-Vialas *et al*., 2020	CADIZ	NA	3km S Alcalá de los Gazules	NA	NA	NA
L: Sánchez-Vialas *et al*., 2020	CADIZ	San Roque	NA	NA	NA	00/05/1973
CS	MALAGA	Alhaurín el Grande	Shrubby area	36.62300, -4.70160	3	29.04.07
CS	MALAGA	Antequera	Acuartelamiento Bobadilla	37.03120, -4.74121	307	NA
CS	MALAGA	Antequera	Cropland	37.06300, -4.71700	3	14.04.15
CS	MALAGA	Campillos	Sub-urban area	37.04603, -4.85733	460	25.05.19
CS	MALAGA	Campillos	Laguna Redonda	37.03010, -4.84400	3	25.05.19
CS	MALAGA	Ciudad Jardín	Arroyo Hondo	36.77359, -4.38472	394	05.04.12
CS	MALAGA	Ciudad Jardín	Near Jardines de San Telmo	36.76744, -4.41804	164	03.04.07
CS	MALAGA	Cortes de la Frontera	Loma de los Pinos	36.56040, -5.39080	3	04.04.15
CS	MALAGA	Fuente de Piedra	Sub-urban area	37.13343, -4.72823	335	NA
CS	MALAGA	La Roda de Andalucía	Mirador la Vicaría	37.13619, -4.75720	397	NA
CS	MALAGA	Málaga	Arroyo las Cañas	36.72195, -4.48979	354	04.03.15
CS	MALAGA	Málaga	Sub-urban area	36.722323, -4.485513	61	15.07.19
CS	MALAGA	Ojén	Sub-urban area	36.56567, -4.85609	100	06.04.08
CS	MALAGA	Parauta	Near Área Recreativa Conejeras	36.66316, -5.09306	1048	13.05.11
CS	MALAGA	Palma-Palmilla	Shrubby area	36.76606, -4.44250	360	22.07.17
CS	MALAGA	Puerto de la Torre	Camino Cupiana	36.75087, -4.49657	376	19.03.21
CS	MALAGA	Sierra de Yeguas	Near Camino de Campillos	37.107585, -4.829026	3	NA
CS	MALAGA	Tolox	Mirador el Cuco	36.71058, -4.98980	381	14.03.16
CS	MALAGA	Yunquera	Mirador Luis Ceballos	36.71734, -4.96470	3	25.05.13
CS	MALAGA	Yunquera	Near Puerto Saucillo	36.71040, -4.96685	1099	03.05.14
CS	MALAGA	Yunquera	Parque Natural Sierra las Nieves	36.71142, -4.96696	1189	26.03.16
L: Sánchez-Vialas *et al*., 2020	MALAGA	NA	Sierra de las Nieves	NA	NA	25.04.91
L: Sánchez-Vialas *et al*., 2020	MALAGA	Montecorto	NA	NA	NA	NA
L: García-París, 1998	MALAGA	NA	Near Málaga, see Fig. 1	NA	NA	NA

L: Pérez-Moreno *et al.*, 2004	MALAGA	Sierra de Ronda	NA	NA	NA	08.04.82
L: Sánchez-Vialas *et al.*, 2020	GRANADA	Santa Cruz Comercio	NA	NA	NA	NA

Table S2. List of specimens studied in the field in which the color of the banding was noted. The observations are divided between two classes, Orange (O) which is represented on the map with orange dots and Red (Red) represented on the map with red dots. Only those individuals from the sampling campaigns were included in the study as the colors could not be standardized from photographs provided by third parties.

Source	Province	Municipal district	Location	X, Y	Colour
F	CADIZ	Alcalá de los Gazules	El Algibe	36.44570, -5.74695	O
F	CADIZ	Algeciras	Sierra de la Plata	36.11251, -5.77617	R
F	CADIZ	Arcos de la Frontera	Arroyo del Salado	36.74120, -5.85514	O
F	CADIZ	Barbate	Sierra del Retín	36.17378, -5.84883	R
F	CADIZ	Chiclana de la Frontera	East peri-urban area	36.41881, -6.12198	O
F	CADIZ	Chiclana de la Frontera	South-West peri-urban area	36.41452, -6.14204	O
F	CADIZ	Chiclana de la Frontera	Torre del Puerco	36.33004, -6.16010	O
F	CADIZ	Conil de la Frontera	Fuente del Gallo	36.29054, -6.10900	O
F	CADIZ	Jerez de la Frontera	Area Sur Shopping centre	36.69224, -6.15621	O
F	CADIZ	Jerez de la Frontera	Arroyo Canaleja, South stretch	36.67779, -6.09269	O
F	CADIZ	Jerez de la Frontera	Arroyo Canaleja, East stretch	36.67972, -6.09339	O
F	CADIZ	Jerez de la Frontera	Arroyo de la Loba	36.69169, -6.16478	O
F	CADIZ	Jerez de la Frontera	Campiña del Área Norte	36.68620, -6.17414	O
F	CADIZ	Jerez de la Frontera	Campiña del Área Sur	36.69996, -6.15733	O
F	CADIZ	Jerez de la Frontera	Cartuja Santa María Defensión	36.65135, -6.10955	O
F	CADIZ	Jerez de la Frontera	El Pedroso	36.52443, -5.98691	O
F	CADIZ	Jerez de la Frontera	Laguna de Medina	36.61580, -6.06087	O
F	CADIZ	Jerez de la Frontera	Zoological Park parkings	36.69006, -6.15332	O
F	CADIZ	Línea la Concepción	Sierra Carbonera	36.19398, -5.35895	R
F	CADIZ	Los Barrios	La Teja, Alcornocales Nat. Park	36.28370, -5.57462	R
F	CADIZ	Medina Sidonia	Arroyo del Azúcar	36.46683, -5.91008	O
F	CADIZ	Medina Sidonia	Arroyo Golondrina/Croplands	36.42423, -5.90806	O

F	CADIZ	Medina Sidonia	Colada de la Espartera	36.43629, -6.02801	O
F	CADIZ	Medina Sidonia	Croplands near Saltillo	36.45661, -5.94742	O
F	CADIZ	Medina Sidonia	Croplands near Saltillo (2)	36.46475, -5.95086	O
F	CADIZ	Paterna de Rivera	Arroyo Pozomedina/ croplands	36.52451, -5.87369	O
F	CADIZ	Puerto Real	Peri-urban area	36.53215, -6.17407	O
F	CADIZ	Trebujena	South croplands	36.85740, -6.19088	O?
L: Cortés-Fossati, 2018	CADIZ	Medina Sidonia	Arroyo del Saltillo	36.45757, -5.94340	O
L: Cortés-Fossati, 2018	CADIZ	Puerto Real	East croplands	36.53127, -6.16051	O
L: Cortés-Fossati, 2018	CADIZ	Puerto Real	Parque de Entrevías	36.53636, -6.19546	O
L: Cortés-Fossati, 2018	CADIZ	Sanlúcar de Barrameda	Las Dunas industrial area	36.75019, -6.34113	R

Assessing the distribution of the Andalusian endemic *Berberomeloe payoyo* Sánchez-Vialas et al., 2020 (Coleoptera: Meloidae), with comments on its ecology

Fernando Cortés-Fossati

Appendix Fig. S2

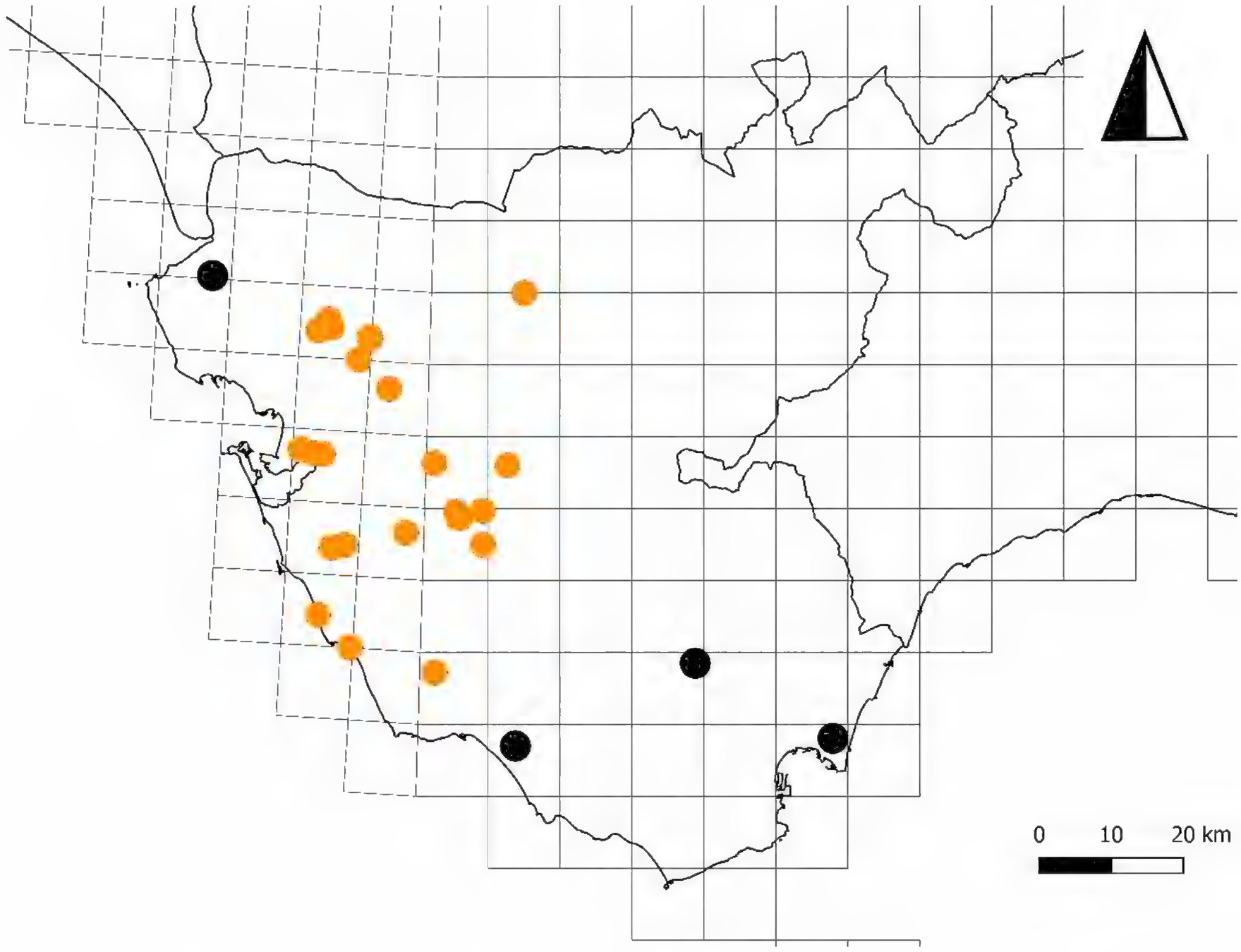


Fig. S2. Mapping of specimens studied on field divided by colouration in the post-tergal banded pattern. The observations are divided between with orange dots (populations with orange bands and black dots (populations with red bands) represented on the map with red dots. Only those individuals from the sampling campaigns and Cortés-Fossati, 2018 were included in the study as the colors could not be standardized from photographs provided by third parties. According to citizen science data, which have not been taken into account in the plot because it cannot be corroborated – since despite having testimonies and photos the colors have not been normalized with a scale – the red individuals would be confined to the northern part of the province and the southern part of the same Strait Zone), leaving the central strip of the province dominated by populations of orange coloration, thus being probably the most widespread coloration.



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Research article

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Type specimen designation for *Onthophagus* (*Colobonthophagus*) *aenescens* (Wiedemann, 1823) and *O.* (*Colobonthophagus*) *urellus* Boucomont, 1920 with notes on the synonymy (Coleoptera: Scarabaeidae: Scarabaeinae)

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Abstract. The taxonomic position of four species of *Onthophagus* (*Colobonthophagus*) Balthasar, 1963 was studied. The neotype of *O.* (*C.*) *aenescens* (Wiedemann, 1823) is designated here, with *O.* (*C.*) *volucer* Balthasar, 1959 as a junior subjective synonym of this species. Furthermore, *O.* (*C.*) *usurpator* Balthasar, 1960 was found to be a junior subjective synonym of *O.* (*C.*) *urellus* Boucomont, 1920. The lectotype and two paralectotypes of *O.* (*C.*) *urellus* Boucomont, 1920 are designated. We show the first record of *O.* (*C.*) *urellus* of Nepal and the Palaearctic region.

Key words. Taxonomy, types, new synonymy, neotype designation, lectotype designation, Onthophagini, Oriental Region, Palaearctic Region.

INTRODUCTION

Onthophagus (*Colobonthophagus*) *aenescens* (Wiedemann, 1823) was originally described as *Copris aenescens* based on five male specimens from Bengal (Wiedemann 1823: 15). During the 1943 bombardment of Hamburg the original type series was lost (Abraham & Husemann pers. comm.). Weidner (1976: 87) stated: "Die Coleopterensammlung des Zoologischen Museums Hamburg wurde bis auf die in Alkohol aufbewahrten Larven 1943 beim Brand des Museums vollständig vernichtet." – (translated from German: The collection of beetles at the Zoological Museum of Hamburg was completely destroyed in the fire at the Museum in 1943, except for the larvae preserved in alcohol.).

The original names *Copris aenescens* Wiedemann, 1823 (p. 177, Nr. 694/695) and *Onthophagus aenescens* (p. 232, Nr. 1624/1625) are not recorded in the catalogue "Verzeichnis der Typen und Typoide" (Weidner 1976: 134).

According to Evenhuis (2008) and the rules of ICZN (1999), a neotype should be designated if the original type series is lost or damaged and designation of the neotype is necessary for clarification of taxonomic status of the species. The position of *O. aenescens* in the subgenus *Colobonthophagus* Balthasar, 1963 (Scheuern, 1995) and the status of *Onthophagus* (*Colobonthophagus*) *volucer* Balthasar, 1959 syn. nov. as a junior subjective synonym of *O.* (*C.*) *aenescens* (Wiedemann, 1823) call for the designation of the neotype for the correct application of the specific name.

After studying the holotype of *Onthophagus volucer* Balthasar, 1959, and 155 specimens of *Onthophagus* (*C.*) *aenescens* (Wiedemann, 1823), we are convinced that this taxon is a junior subjective synonym of *O.* (*Colobonthophagus*) *aenescens* (Wiedemann, 1823). Both taxa show similar morphology of the head, punctation of the pronotum, characteristics of elytra and surface of the body (Fig. 1A–F). The aedeagus and the lamella copulatrix also show the same structure (Fig. 2A, C). Furthermore, the type localities of both taxa are situated close to each other (Fig. 6).

We also find *O.* (*Colobonthophagus*) *usurpator* Balthasar, 1960 to be a junior subjective synonym of *O.* (*Colobonthophagus*) *urellus* Boucomount, 1920; this is based on examination of three syntypes of *O.* (*C.*) *urellus*, seven specimens from South India, one male from Nepal and the holotype of *O.* (*C.*) *usurpator*. Both taxa show similarities in all morphological characters of the genitalia, pronotum and in the punctation. The armatures of the head are different from other species of the subgenus (Figs 3A–F, 4A, C). In the present study we designate the lectotype (♂ major) of *Onthophagus* (*Colobontho-*

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phagus) *urellus* Boucomount, 1920 deposited at the Muséum national d'Histoire naturelle, Paris (MNHN).

This paper provides an overview of the distributions of the two *Onthophagus* species in the Oriental and Palaearctic regions (Middle Asian regions) (Fig. 6).

The revision of the subgenus *Colobonthophagus* Balthasar, 1963 by Scheuern (1995, 1996) presents 27 species with keys separating *O.* (*C.*) *aenescens* and *O.* (*C.*) *urellus* from other species.

MATERIAL AND METHODS

The following acronyms identify the collections housing the examined material (curators in parentheses):

cAS	=	André Skale, Gera, Germany
cAW	=	Andreas Weigel, Wernburg, Germany
cAK	=	Andreas Kopetz, Eischleben, Germany
cAN	=	Alexander Napolov, Riga, Latvia
cDJ	=	Dieter Jungwirth, Ingolstadt, Germany
cJS	=	Joachim Schönfeld, Sinzig, Germany
cOH	=	Oliver Hillert, Schöneiche near Berlin, Germany
cPS	=	Paul Schoolmeesters, Herent, Belgique
HNHM	=	Hungarian Natural History Museum, Budapest, Hungary (Otto Merkl)
MFNB	=	Museum für Naturkunde Berlin, Germany (Johannes Frisch)
MHNG	=	Muséum d'Histoire Naturelle de Genève, Switzerland (Ivan Löbl)
MNHN	=	Muséum national d'Histoire naturelle, Paris, France (Olivier Montreuil)
NHMB	=	Naturhistorisches Museum, Basel, Switzerland (Matthias Borer)
NHMD	=	Natural History Museum of Denmark, Copenhagen, Denmark (Alexey Solodovnikov)
NMEG	=	Naturkundemuseum, Erfurt, Germany (Matthias Hartmann)
NMPC	=	National Museum, Prague, Czech Republic (Jiří Hájek)
PIME	=	Pontificio Istituto Missioni Estere (P.I.M.E.), Entomological Museum, Memphis, Detroit, Michigan (USA) Coll. Dr Carlo Brivio
RBINS	=	Royal Belgian Institute of Natural Sciences, Bruxelles, Belgium (Alain Drumont)
ZFMK	=	Zoologisches Forschungsmuseum Alexander Koenig, Bonn, Germany (Dirk Ahrens)
ZMH	=	Zoologisches Museum Hamburg, Germany (Martin Husemann)

Altogether, 156 specimens of *O.* (*C.*) *aenescens* and 12 specimens of *O.* (*C.*) *urellus* were studied (see material listed below). Remarks of the authors and comments are indicated in parentheses. The exact label data are cited for the type material only; individual labels are indicated (only for types) by double slash (//), individual lines on every label by single slash (/), [p] = preceding data within quotation marks are printed, [hw] = preceding data within quotation marks are handwritten.

Taxonomy and distribution

Onthophagus* (*Colobonthophagus*) *aenescens (Wiedemann, 1823)
Figs 1A–F, 2A–D, 5A–C, 6

Copris aenescens Wiedemann, 1823:13 (original description).
Onthophagus volucer Balthasar, 1959 [syn. nov.]: 190 (original description).
Onthophagus (s.str.) aenescens: Balthasar 1963: 264 (redescription).
Onthophagus (s.str.) *volucer* Balthasar, 1963: 586 (redescription); Bezdek & Hájek 2013:428 (catalogue, status); Frey 1973: 102 (redescription, type material).
Onthophagus (*Colobonthophagus*) *aenescens*: Scheuern 1995: 416 (stat. nov., key); Mittal 2000: 263 (distribution); Kabakov 2006: 162 (status); Mittal & Jain 2015: 395 (distribution); Ziani & Bezdek, 2016: 175 (catalogue, distribution); Löbl et al. 2006: 163 (catalogue, distribution).

Type locality of *O.* (*Colobonthophagus*) *aenescens* (Wiedemann, 1823): Bengalia, Burma.

Type material examined (2 specs)

Onthophagus aenescens

Neotype

BENGALEN • ♂ (NHMD, here designated): "Bengal. / Septbr. 1810. [hw] // Zool. Museum DK Copenhagen [p] / *O.* (*Colobonthophagus*) [p] / *aenescens* (WIED.) [hw] / J.SCHEUERN det.19 [p] 96 [hw] // *Onthophagus* (*Colobonthophagus*) [p, fat] // *aenescens* (WIEDEMANN, 1823) [p] // NEOTYPUS ♂ desig. 2022 [p, fat] // J. SCHÖNFELD & D. ROHWEDDER [p, red label]".

Onthophagus volucer

Holotype

BURMA • ♂ (NMPC): "Burma [Myanmar] / Tenass[erin] [hw] // Hoefer [hw] // Mus. Nat. Pragae [p] / 65 845 [hw] / Inv. [p, red label] // *Onthophagus* / *volucer* / ♂ n.sp. / Balth.[hw] / Holotypus [p, pink label] // *O.* (*Colobonthophagus*) [p] / *aenescens* WIED.) [hw] / J. SCHEUERN det.19 [p] 96 [hw] // *volucer* BALTH. / Syn.nov. / J. SCHEUERN det. [p] 96 [hw] // *O.* (*Colobonthophagus*) / *aenescens* / (WIEDEMANN 1823) ♂ / J. SCHÖNFELD det. 2017 [p]; // *O.* (*Colobonthophagus*) / *volucer* / BALTHASAR 1959/ syn. nov. / J. SCHÖNFELD det. 2017 [p]".

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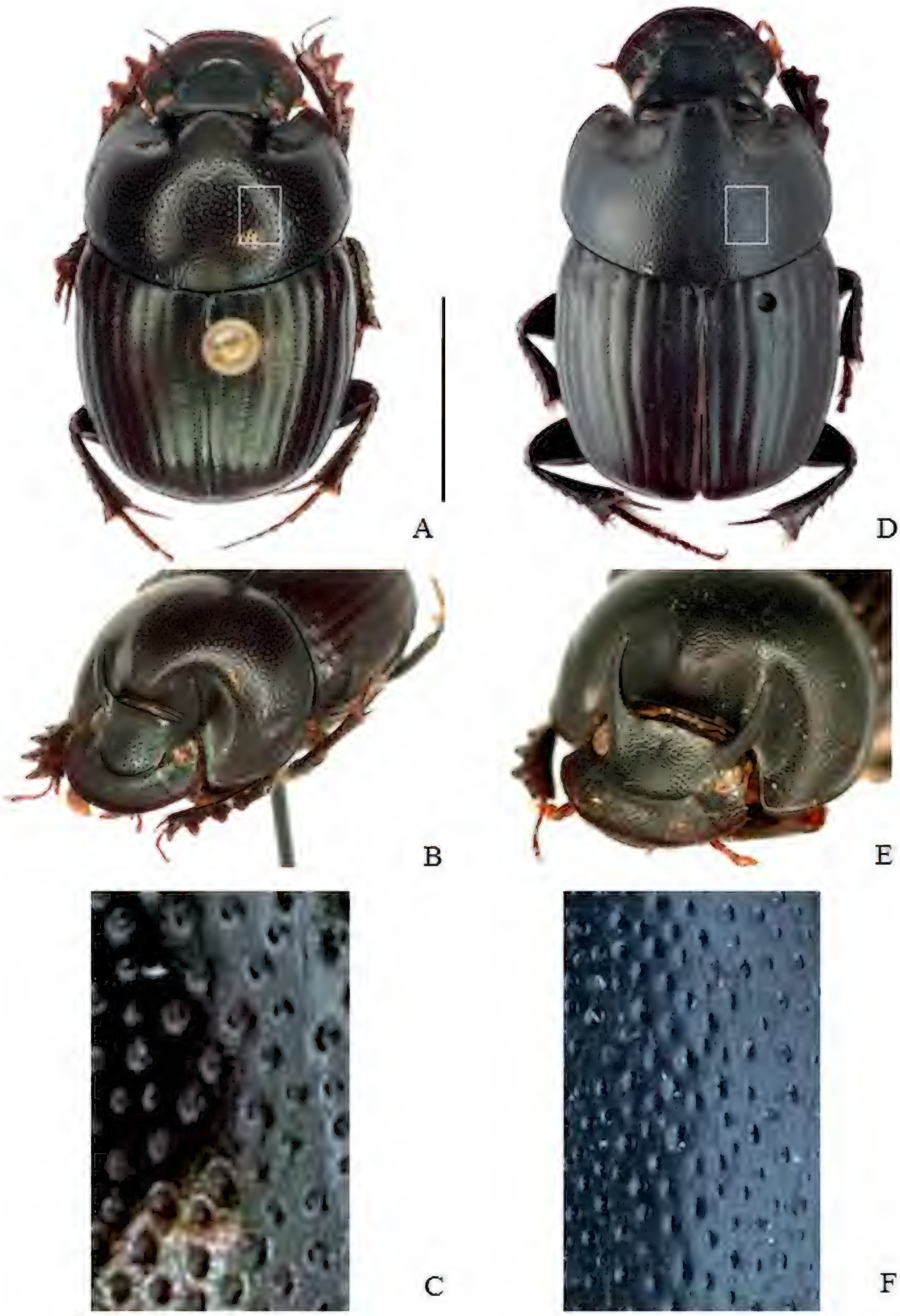


Fig. 1. A–C. *Onthophagus* (*Colobonthophagus*) *aenescens* (Wiedemann, 1823), neotype, ♂. **D–F**. *Onthophagus* (*Colobonthophagus*) *volucer* Balthasar, 1959 syn. nov., ♂. **A, D**. Habitus, dorsal view. **B, E**. Habitus, fronto-ventral view. **C, F**. Pronotal sculpture in dorso-lateral view with close-up of the punctation (C = top; F = sloping). Scale = 5 mm.

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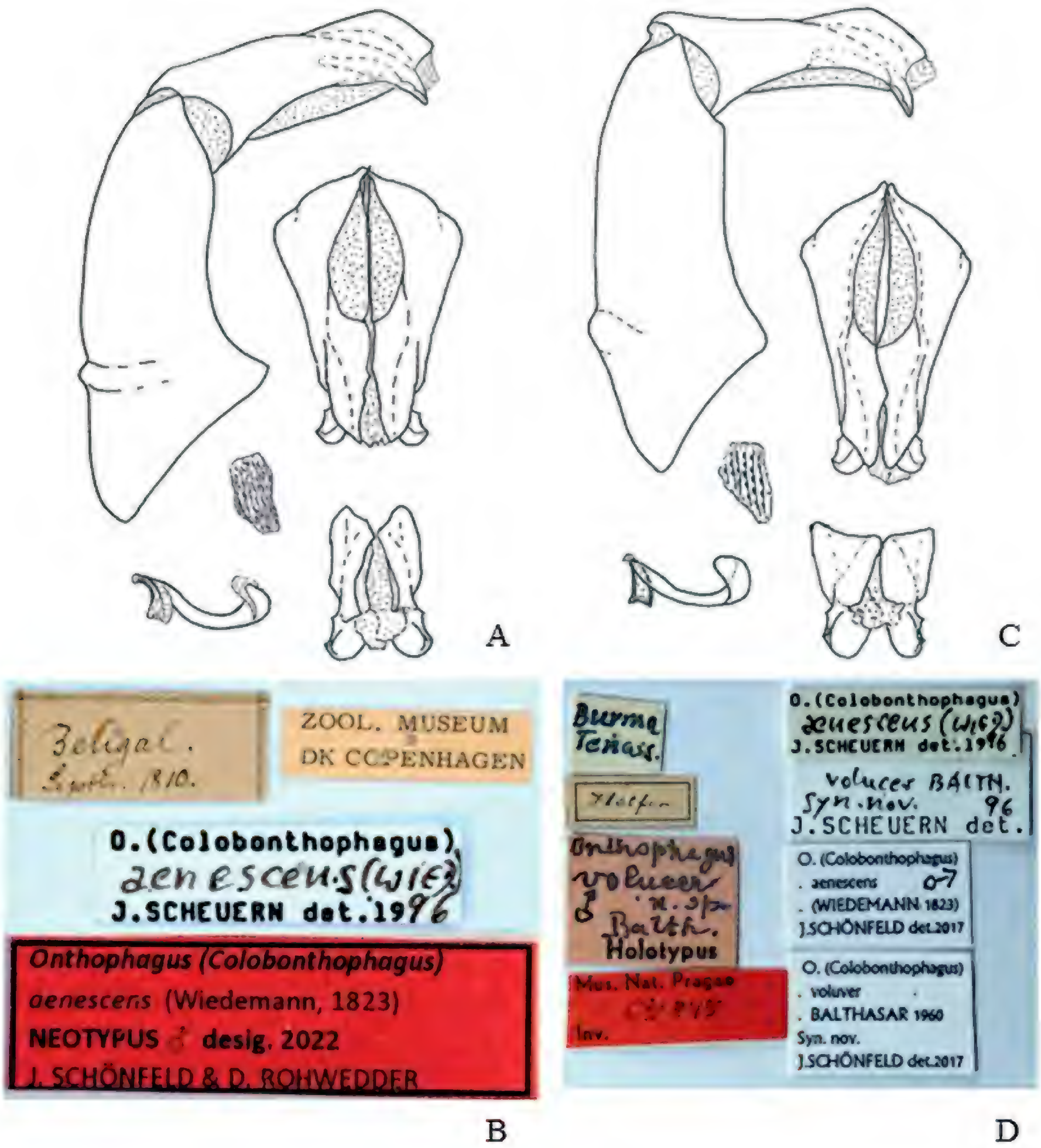


Fig. 2. A–B. *Onthophagus* (*Colobonthophagus*) *aenescens* (Wiedemann, 1823), neotype, ♂. **C–D**. *Onthophagus* (*Colobonthophagus*) *volucer* Balthasar, 1959 syn. nov., ♂. **A, C**. Left: Aedeagus, lateral view, raspula, lamella copulatrix, ventral view; right: Parameres, dorsal view & apical view. **B, D**. Labels.

Other material examined (154 specs)

BANGLADESH • EAST PAKISTAN [Bangladesh], Dinajpur, X-1969, Barbe', Paratype ♀, *Onthophagus volucer* Balt., G. FREY 1972; 1♀ (NHMB). EAST PAKISTAN [Bangladesh], Dinajpur, IV-1970, Barbe', *Onthophagus volucer* Balt. ♂, G. FREY 1969; 1♂ (NHMB). Bengala: Boldipukur, 6.1964 Grest leg., *O. aenescens* (WIED.) det. PITTINO; 2♂, 1♀ (cRP).

INDIA • [Nr.]26884, *flavicornis* meg. Germ., Zool. Mus. Berlin; 1♂ (MFNB). Assam, Nr. 26884, Zool. Mus. Berlin; 2♂, 3♀ (MFNB). Assam, Nr. 26884, *aenescens* Wied., West.[ermann], Zool. Mus. Berlin; 1♂ (MFNB). Assam, Westermann, Zool. Museum DK Copenhagen; 1♂ (NHMD), 1♂ (cJS). Assam, Kaziranga, 10.XII.1969, leg. G. PILLERI; 20♂, 34♀ (NMEG), 1♀ (ZFMK), 1♂, 1♀ (cAN), 2♂, 2♀ (cJS). [W Bengal] Barbaria; 1♀ (NHMD). Calcutta, 1938, Coll. Boucomont, Paris; 1♀ (MNHN). Calcutta, Ex Mus. V. LANSB.[ERGE], Coll. Boucomont, Paris; 1♀ (MNHN). Darjeeling D., Sonapur, Mahahandra Riv., Bhakta B., 9.-15.IX.1984; 1♀ (cJS). KHARI, [near] KASHINAGAR. W-BENGAL., leg. 26.I.1950. Rev.S. POLGAR 57, ex coll.: Ch.S.PAPP, *aenescens* Wied.; 1♂ (NHMB). Bengale (Mnisrech),

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aenescens det. Gillet; 1♀ (RBINS). Sirampur, Zool. Museum DK Copenhagen; 1♂ (NHMD), 1♀ (cJS). Sunderbunds, Coll. Boucomont; 1♀ (MFNB). Ex Mus. VAN LANSBERGE, ex coll. R. OBERTHÜR 1952, det. *aenescens* WIED.; 1♂ (MNHN).
Ex Museo E. HAROLD, *aenescens* WIED., G.J. ARROW vidit. 1906, ex Coll R. OBERTHÜR 1952; 1♂ (MNHN). Coll. J. Thomson, Coll.R.I.Sc.N.B.; 1♂ (RBINS). Coll. de Bonneuil, *flavicornis* Le Moult vendit; 1♂ (RBINS). *Onthophagus* (*s.str.*) *volucer* Balth. ♂, Dr. V. Balthasar det. 60; 1♂ (NHMB). Mus. S.S.T.L.; 1♂, 1♀ (NHMD).

NEPAL • Bheri / D: Banke, Nepalganj, Hotel Sneha, 28°02'53"N, 81°36'56"E, 125 m, 05.VII.2009, leg. A. Kopetz, LF #64; 2♂, 1♀ (cAK), 1♀ (cJS). Mahakali / D: Kanchanpur, Mahendranagar, Hotel Sweet Dream, N28°58´13", E81°11´01", 210 m, 02.VII. 2009, leg. A. Kopetz LF ,#60; 1♀ (cAK). Narayani Prov., Sauraha, Royal Chitwan Nat.-P., Rapti River, Ufer, 180 m NN, 27°34'80"N, 84°29'49"E, 18.04.2000, LF [light trap], A. Skale leg.; 2♂, 4♀ (cAS), 1♂, 1♀ (cJS).). Narayani Prov., Sauraha, Royal Chitwan Nat.-P., Rapti River, Ufer, 180 m NN, 27°34'80"N, 84°29'49"E, 18.04.2000, LF [light trap], A. Weigel leg.; 2♂, 2♀ (NMEG), 1♂ (cAW), 2♂ (cJS). Narayani Prov., Sauraha, Royal Chitwan Nat.-P., Rapti River, Ufer, 180 m NN, 27°34'80"N, 84°29'49"E, 18.04.2000, LF [light trap], F. Wolf leg.; 1♂, 1♀ (NMEG), 1♀ (cJS). Narayani Prov., Sauraha, Royal Chitwan Nat.-P., Rapti River, Ufer, 180 m NN, 27°34'80"N, 84°29'49"E, 16.-18.04.2000, LF [Light trap] A. Skale leg.; 1♀ (cAS), 1♀ (cJS), 1♂ (cOH). Narayani Prov., Sauraha, Royal Chitwan Nat.-P., Rapti River, Ufer, 180 m NN, 27°34'51"N, 84°29'30"E, 14.-15.V.2002, HF, leg. A. Kopetz; 1♀ (cAK). Chitwan distr., Royal Chitwan Nat.P., Island Jungle Resort, 29-30.X.1995, leg. L. Peregovits; 2♂, 2♀ (HNHM), 1♂ (ZFMK), 1♂, 2♀ (cJS). Royal Chitwan Nat.-P., 17. / 18.11.1998, SCHOOLMESTERS leg.; 1♀ (cJS). Royal Chitwan N.P., Island Resort, 17.-18.11.1998, [anonymous], 2♂ (cJS). Narayani Zone, Chitwan Distr., Chitwan N.P., Sauraha – Thati Bagh Mara, 200 – 500 m, leg. P. Cechovsky; 1♂, 4♀ (cDJ). Prov. Narayani, Chitwan: Gunganagar, 200 m, 27°39'N, 84°19'E, V.2005, leg. D. Ahrens; 1♀ (NMEG), 1♀ (cJS). Pokhara, 900 m, 2.-3.1984, Bhakta B.; 1♂ (NHMB), 1♂, 1♀ (cJS).

TIBET (China, Xizang) • THIBET, 600/1/ Coll. Melly; 1♂ (MHNG). THIBET, 501/87/ Coll. Jurine, *flavicornis* Germ.; 1♀ (MHNG).

Without exact data

Ex Mus. E. HAROLD, Coll. Boucomont; 5♂ (MNHN).
Bengala, *Aenescens*. ekke Type WIED., Zool. Museum DK Copenhagen; 1♀ (cJS).
Bengalie, Ex Mus. Thorey, BATES, Coll. Boucomont, Paris; 2♂, 2♀ (MNHN). Bengalia, Westermann; 1♀ (NHMD). Bengal. / Septbr. 1810., Zool. Museum DK Copenhagen, *O.* (*Colobonthophagus*) *aenescens* (WIED.); 1♀ (NHMD).

Neotype redescription

Male specimen from Bengal (Figs 1A–C, 2A–B)

Measurements (Fig. 1A–B). Length: 12.2 mm, width: 7.4 mm. Male major with two well developed horns, and pronotum with an anteromedian round prominence; moderately arched, mostly glabrous. Color blackish brown, with very moderately green metallic sheen. In dorsal view eyes broad oval; first elytra interval on base without recess, but in the first quarter with a small longitutinal elevation near suture. Antennal foot-stalks reddish brown, club segments of antenna yellowish.

Head. Clypeus broadly round, margin anteriorly distinctly reflexed, clypeofrontal carina moderately elevated but distinct, circlar, backwards reaching to the bases of two horns on vertex beneath well developed, oval eyes. In frontal view horns slightly divergent on base, softly incurved near apices, obliquely inclined backward. Vertex between horns with a thin, low carena, situated backward. Clypeus densely distinctly rugo-punctate, frons densely rugo-punctate, vertex and genae more densely rugo-punctate, building small, low ridges.

Pronotum (Fig. 1C) with a triangular, rounded anteromedian prominence, longitudinal midline missing; on each side, behind the horns, with a deep depression; anterior angles projected, rounded; lateral margins softly rounded, only slightly sinuate. Base rounded, only in the middle bordered, marginal line reaching the second striae of elytra. The middle of the disc with large, simple rounded, deep punctures; punctures with different diameters, mostly separated by one diameter, becoming compact at a longitudinal area in the middle from anteromedian prominence to the base. Punctures of anterior angles larger, more dense and more shallow, with some yellow, minute setae; depressions with minute, oval punctures. The sharp border of the base of the pronotum with a dense line of large punctures, reaching the hind angles.

Elytra. Striae broad, punctures small, transverse, weakly notching both margins of intervals; 7th striae distinctly curved in the middle, intervals slightly convex, very weakly micro-reticulated, everywhere densely and coarsely punctured, the distances between punctures are shorter than their diameters. The inner intervals with shallow, small punctures, each puncture bears a small granule at its anterior margin. Toward outer intervals the punctures becoming coarser and deeper, without granules, but with very short, fine, yellow-white setae. All intervals apical with some short, yellow setae.

Pygidium carinate at base, weakly convex, micro-reticulated, moderately sparsely punctated. Points moderately

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deep, with different diameters, and sub-regular in distribution, simply rounded, with some short, yellow setae.

PROTIBIAE with four strong outer teeth, apical spur blunt inner side straight, outer side curved to the obtuse tip, slightly bent downward.

METASTERNUM. Anterior declination weakly convex, disc plan, smooth, with a median longitudinal groove, apical ending with an oval depression. Anterior declination and ventral area with minute, shallow punctures.

AEDEAGUS and LAMELLA COPULATRIX (Fig. 2A).

Variation

Measurements (70 ♂♂, Length 10.8–12.2 mm; 86 ♀♀, Length 9.1–12.5 mm). In female and minor male vertex with reduced horns, with a narrow straight lamina between them. Pronotum with slight depressions and reduced anteromedian prominence, notched in female. Clypeus of female with very coarse, transverse rugose or subrugose punctures. There is only a weak tendency to variation in the punctures on the elytra.

Differential diagnosis

O. (*C.*) *aenescens* is very similar to *O.* (*C.*) *dama* (Fabricius, 1798) and *O.* (*C.*) *bengalensis* Harold, 1886. *O.* (*C.*) *aenescens* shows on dorsal surface large punctures separated from each other by approximately 1 diameter of a puncture. *O.* (*C.*) *bengalensis* and *O. (C.) dama* show very fine and sparse punctures separated further from each other (1–3 puncture diameters). *O.* (*C.*) *bengalensis* and *O.* (*C.*) *aenescens* have a completely bordered base of the pronotum, while *O.* (*C.*) *dama* has only a short remnant of a border in the middle of the base. The body of *O.* (*C.*) *aenescens* and *O.* (*C.*) *dama* show a green or brownish metallic sheen, the body of *O.* (*C.*) *bengalensis* is black without metallic sheen.

Distribution

Bangladesh (East Pakistan), India, Myanmar, Nepal, Tibet. (type locality of *O.* (*C.*) *volucer* Balthasar, 1959 syn. nov.: Burma [Myanmar], Tenass[erim]) (Fig. 6).

Taxonomic remarks

Based on four complete and one partial specimen Wiedemann (1823) described *Copris aenescens* from "Bengalia" and deposited the type material at the Zoologisches Museum Hamburg, where it was destroyed by fire in 1943. We have not found any types of this taxon in the Zoologisches Museum Hamburg. Only in MFNB, NHMB (Coll. FREY) and NHMD we have found some determined specimens, but no valid types. As no original material of *Onthophagus (Colobonthophagus) aenescens* exists, we here designate a neotype from specimens collected in the type locality Bengalia to clarify the taxonomic status and for nomenclatural stability according to Article 75.3 of the Code (ICZN 1999). The neotype is chosen from the collection of NHMD and deposited at the Natural History Museum of Denmark, Copenhagen (NHMD).

However, it was necessary to study the type material of *O.* (*C.*) *voluver* Balthasar, 1959 syn. nov. and a lot of well determined material of *O.* (*C.*) *aenescens* in order to eliminate confusions in Balthasar's key (Balthasar, 1963: 210, alt. 180 (193)) and with other closely related species.

The present study is based on the examination of 156 specimens of *O.* (*Colobonthophagus*) *aenescens* (Wiedemann, 1823) from Bangladesh, India, Myanmar, Nepal and Tibet. The old historic region Bengalia had no clearly defined borders, it apparently included several regions today called Bangladesh, West Bengal and some parts of Bihar, Jharkharnd, Tripuru and Odisha.

Some notes on the distribution have been published, but we are not in the position to verify them: Mittal (2000: 263): Himachal Pradesh; Mittal & Jain (2015: 395): Himachal Pradesh (Una), Uttarakhand (Dehradun), Uttar Pradesh (Faizabad), Bihar (Chapra, Pusa), W. Bengal (Purnea dist., Kolkata); Löbl et al. (2006: 163); Ziani & Bezděk (2016: 175): The same Indian states and Pakistan.

Balthasar described *O.* (*C.*) *voluver* syn. nov. based on a single male specimen (holotype), the female was unknown. Frey (1973: 102) studied 3 ♂♂ and 2 ♀♀ from East Pakistan (Bangladesh, Dinajpur, X.1969), described the female of *O.* (*C.*) *voluver* and incorrectly designated an allotype and paratypes, which are not valid as such. These specimens are deposited as follows: allotype in collection Dr. Carlo Brivio (P.I.M.E.), paratypes in collection G. Frey (NHMB).

The examined male holotype of *O. (C.) voluver* is conspecific with the series of specimens and the neotype of *O.* (*C.*) *aenescens*. They share the same morphology of aedeagus, lamella copulatrix, structures of the head, vertex armatures, pronotum punctation and body coloration. We cannot find any morphological characteristics to separate *O.* (*C.*) *aenescens* Wiedemann, 1823 from *O.* (*C.*) *volucer* Balthasar, 1959. Consequently, we consider *O.* (*C.*) *volucer* a junior subjective synonym of *O.* (*C.*) *aenescens*.

The neotype of *O.* (*C.*) *aenescens*, here designated, is chosen from the type locality Bengalia. Notable entomologists, for example G.J. Arrow, V. Balthasar, A. Boucomont, G. Frey, E. Harold and R. Pittino, have determined specimens especially from Bengalia as *O.* (*C.*) *aenescens*. They correspond with the diagnosis of the subgenus *Colobonthophagus* of Scheuern (1995), the diagnostic characters used in Balthasar (1963), the above redescribed taxon, and differs from all other species of the genus *Onthophagus*.

Among other morphological characters, all species of subgenus *Colobonthophagus* have large eyes with a horn or a small bulge beneath, and a swelling or a longish

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bulge on the base of the first elytral interval. The key of Scheuern (1995) listed characters of *O.* (*C.*) *aenescens*: Black or brownish, often with a metallic green sheen. Clypeus clearly rounded, base of pronotum only in the middle with clear marginal line. Dorsal surface everywhere densely and coarsely punctured, the distances of punctures are shorter than their diameters.

Onthophagus* (*Colobonthophagus*) *urellus Boucomont, 1920
(Figs 3A–F, 4A–D, 5D–F, 6)

Onthophagus urellus Boucomount, 1920: 310 (original description).
Onthophagus urellus var. *nilgirinus* Arrow, 1931: 298 (description, var.).
Onthophagus (*s.str.*) *usurpator* Balthasar, 1959: 190 (original description) [syn. nov.].
Onthophagus (*Colobonthophagus*) *urellus*: Scheuern 1995: 418 (listing, key, pictured); Scheuern 1996: 12 (key).
Onthophagus (*Colobonthophagus*) *usurpator*: Bezděk & Hájek 2013: 427 (status, catalogue); Mittal & Jain 2015: 402 (distribution).

Type locality of *O.* (*Colobonthophagus*) *urellus* Boucomont, 1920: BURMA [Myanmar]: Pegu.

Type material examined (4 specs)

Onthophagus (*Colobonthophagus*) *urellus*
Lectotype
MYANMAR • 1♂ major (MNHN, here designated): "Pegu [Myanmar] / Inde [hw] // Boucomont det. 19 [p] 19[hw] / *Onthophagus* / *urellus* n.sp. [hw] // TYPUS [p, pink label] // MUSÉUM PARIS / 1936 / COLL. A. BOUCOMONT [p] // SYNTYPE [p, red label]] // SYNTYPE / *Onthophagus* / *urellus* Boucomont, 1920 // MNHN / EC10031 // *Onthophagus* (*Colobonthophagus*) [p,fat] // urellus A. BOUCOMONT, 1920 [p] // LECTOTYPUS ♂desig. 2022 [p,fat] // J. SCHÖNFELD & D. ROHWEDDER [p, red label]".

Onthophagus (*Colobonthophagus*) *urellus*
Paralectotypes
MYANMAR • 1♂, 1♀ (MNHN, here designated): 1♂ minor (MNHN): "Pegu [Myanmar] / India [p] // Boucomont det. 19 [p] 20[hw] / *O. urellus* B. [hw] // ♂ [p] // TYPUS [p, pink label] // MUSÉUM PARIS / 1936 / COLL. A. BOUCOMONT [p] // SYNTYPE [p, red label] // SYNTYPE / *Onthophagus* / *urellus* Boucomont, 1920 // MNHN / EC10033 // *Onthophagus* (*Colobonthophagus*) [p,fat] // *urellus* A. BOUCOMONT, 1920 [p] // LECTOTYPUS ♂ desig. 2022 [p, fat] // J. SCHÖNFELD & D. ROHWEDDER [p, red label]". 1♀ (MNHN): "Pegu [Myanmar] / India [p] // Boucomont det. 19 [p] 20 [hw] / *O. urellus* [hw] // ♀ [p] // TYPUS [p, pink label] // MUSÉUM PARIS / 1936 / COLL. A. BOUCOMONT [p] // SYNTYPE [p, red label] // SYNTYPE / *Onthophagus* / *urellus* Boucomont, 1920 // MNHN / EC10032 // *Onthophagus* (*Colobonthophagus*) [p, fat] // *urellus* A. BOUCOMONT, 1920 [p] // PARALECTOTYPUS ♀ desig. 2022 [p, fat] // J. SCHÖNFELD & D. ROHWEDDER [p, red label]".

Onthophagus (*Colobonthophagus*) *usurpator*
Holotype
INDIA • ♂ (NMPC): "INDIA / LIDIO CIPRIANI [p] // COORG/ PONNAMPET / M. GHAT. XII-1934 [p] // *Onthophagus* / *s.str.* ♂ // *usurpator* / Balth.[hw] / HOLOTYPUS [p] [handwritten corrections, pink label] // Mus. Nat. Pragae/ 65844 / Inv. [p, red label] // *O.* (*Colobonthophagus*) [p] / *urellus* BOUC. ♂ [hw] / J. SCHEUERN det. 19 [p] 96 [hw] // *usurpator* Balth. / syn. nov. [hw] / J. SCHEUERN det. [p] 96 [hw] // *O.* (*Colobonthophagus*) / *urellus* ♂ / BOUCOMONT 1919 / J. SCHÖNFELD det.2017 [p] // *O.* (*Colobonthophagus*) / *usurpator* / BALTHASAR 1960 / Syn. nov. / J. SCHÖNFELD det. 2017 [p]".

Other material examined (8 specs)
INDIA • Bombay [Mumbai], *Onth.* (*Colob.*) *urellus* BOUC. var. *nilgirinus* ARROW, ♀; 2♀ (cJS). S. Coorg-Ammatti_[Ammathi], 3100 ft., XI-1952 P.S. Nathan, Coll.R.I.Sc.N.B.; 1♂ (cJS). Ghates, R.P.F. Tabourel, VII-IX 1898, MUSÉUM PARIS 1952, Coll.: R. OBERTHÜR, *Onthophagus urellus* ♂, det. G. Frey, 1955; 1♂ (NHMB). NILGIRI HILLS, DEVALA, 3200 ft.,??.10.1960, (ex PSCH); 1♀ (cJS). Nilgiri Hills, H.-L. Andrewes, Andrewes Bequest., B-M. 1922-221, Coll.R.I.Sc.N.B.; 1♀ (RBINS). Tavargatti, Belgaum Div., ex Dehra Dun Coll. B.M.1931-2., B.M. Bhatia., *Onthophag. urellus* Bouc., G. J. Arrow det.; 1♂ (NHMB).
NEPAL • P: Mahakali, D: Kanchanpur, vic. Mahendranagar, Suklaphanta Nat. Res., Peters Area, Dsauda river, 160 m, 01. VII. 2017, # 17-19. leg. A. Weigel, second. forest riverside, 28°53'51"N 80°13'39"E, LFF [light trap]; 1♂ (NMEG).

Distribution
South India: Western Ghats, Myanmar, Nepal (first record, see material examined), first record of Palaearctic region (Fig. 6).

Remarks
The present study is based on the examination of eight specimens from South India (Western Ghats), one male from Nepal, and three MNHN syntypes (2 ♂♂, 1 ♀♀) of *Onthophagus* (*C.*) *urellus* from Pegu [Myanmar] of which we designate here a lectotype (♂). Arrow (1931: 298) described the variety *nilgirinus* from South India, Nilgiri Hills. There are only minor differences between the types and the material from South India. In the Cata-

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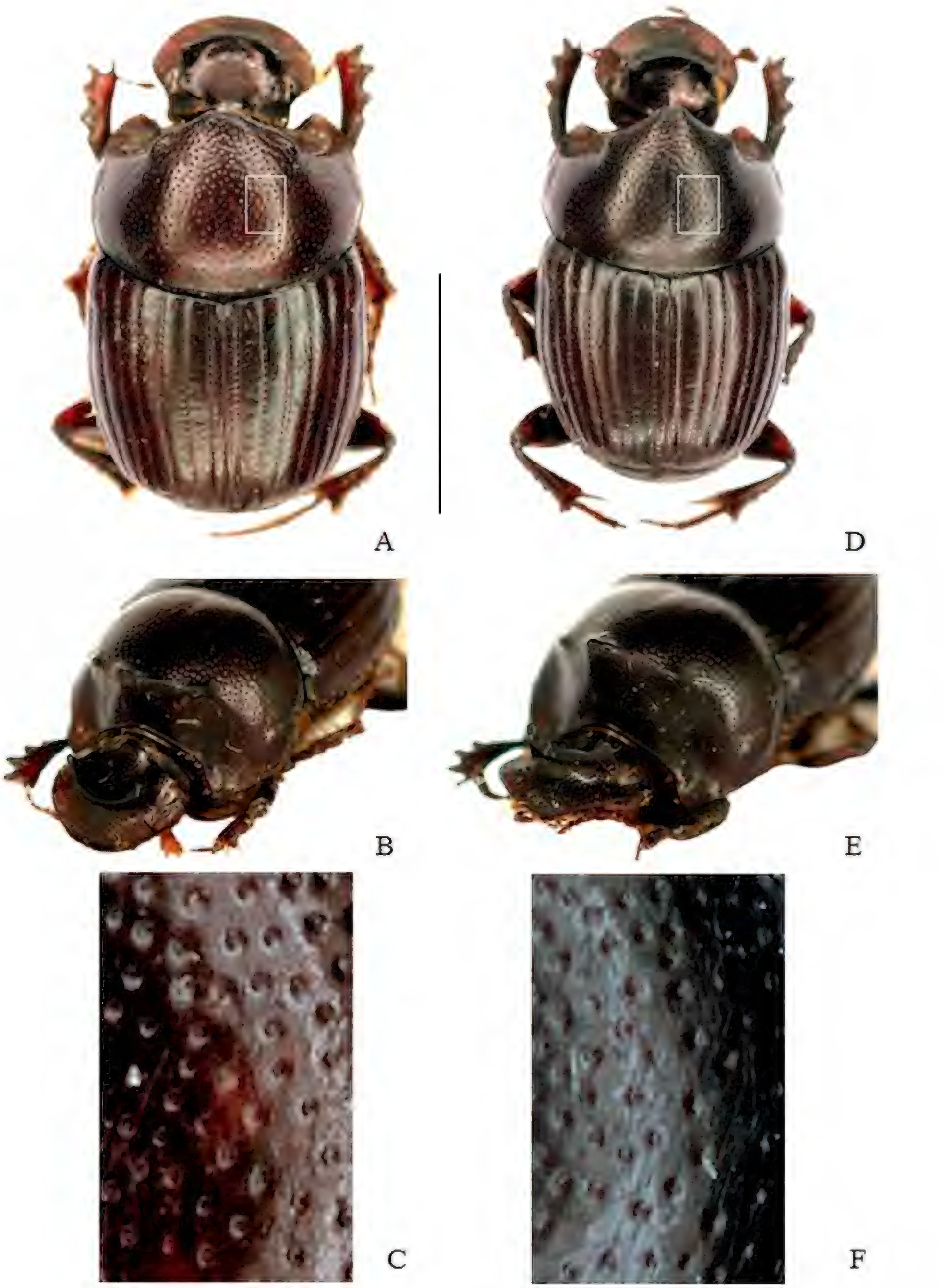


Fig. 3. A–C. *Onthophagus* (*Colobonthophagus*) *urellus* Boucomont, 1920, neotype, ♂. **D–F**. *Onthophagus* (*Colobonthophagus*) *usurpator* Balthasar, 1959 syn. nov., ♂. **A, D**. Habitus, dorsal view. **B, E**. Habitus, fronto-ventral view. **C, F**. Pronotal sculpture in dorso-lateral view (top) with close-up of the punctation. Scale = 5 mm.

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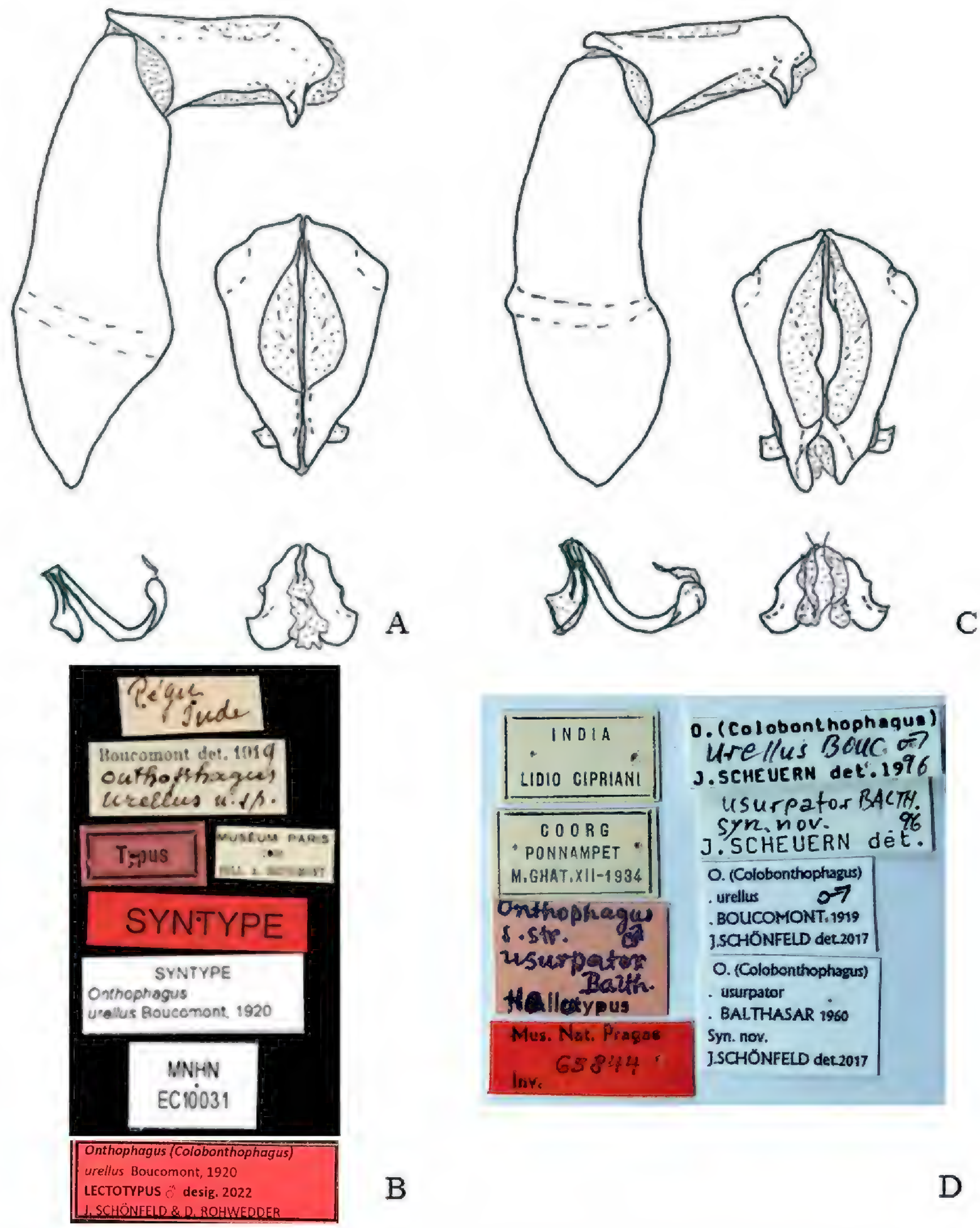


Fig. 4. A–B. *Onthophagus* (*Colobonthophagus*) *urellus* Boucomont, 1920, neotype, ♂. C–D. *Onthophagus* (*Colobonthophagus*) *usurpator* Balthasar, 1959 syn. nov., ♂. **A, C**. Left: Aedeagus, lateral view, lamella copulatrix, ventral view; right: Parameres, dorsal view & apical view. **B, D**. Labels.

logue of Life (2018, Annual Checklist) the var. *nilgirinus* is listed as synonym of the nominotypical species.

The taxon *Onthophagus usurpator* Balthasar, 1959 was described based on a single male (holotype) collected in South India, Ponnampet / M. Ghat. This examined holotype is conspecific with the lectotype of *Onthophagus* (*C.*) *urellus*. They share the shape of the aedeagus, pronotum, and punctation of the body. There are, however, considerable differences in the armature of the head, a phenomenon exhibited by most other species of the subgenus *Colobonthophagus* (Scheuern, 1995). Mittal (2015) has listed *Onthophagus* (*Colobonthophagus*) *urellus* Boucomont, 1920 from Tamil Nadu (Nilgiri Hils), Kerala (Thirunelly forest) and *Onthophagus usurpator* from Kerala, (Thirunelly forest). Karnataka (Coorg Ponnampet) was the type locality of *O.* (*C.*) *usurpator*.

In Nepal, *O.* (*C.*) *urellus* was collected using a light trap in young secondary forest with herds of cattle on the right side of the river (A. Weigel pers. comm.). This record provides the only ecological hint on this species. We determined specimens from Western Ghats as *O.* (*C.*) *urellus,* but we did not see any female of *O.* (*C.*) *usurpator* Balthasar, 1959.

The discontinuous distribution between southern India, Nepal and Myanmar needs to be verified by more material, especially from Myanmar or adjacent countries.

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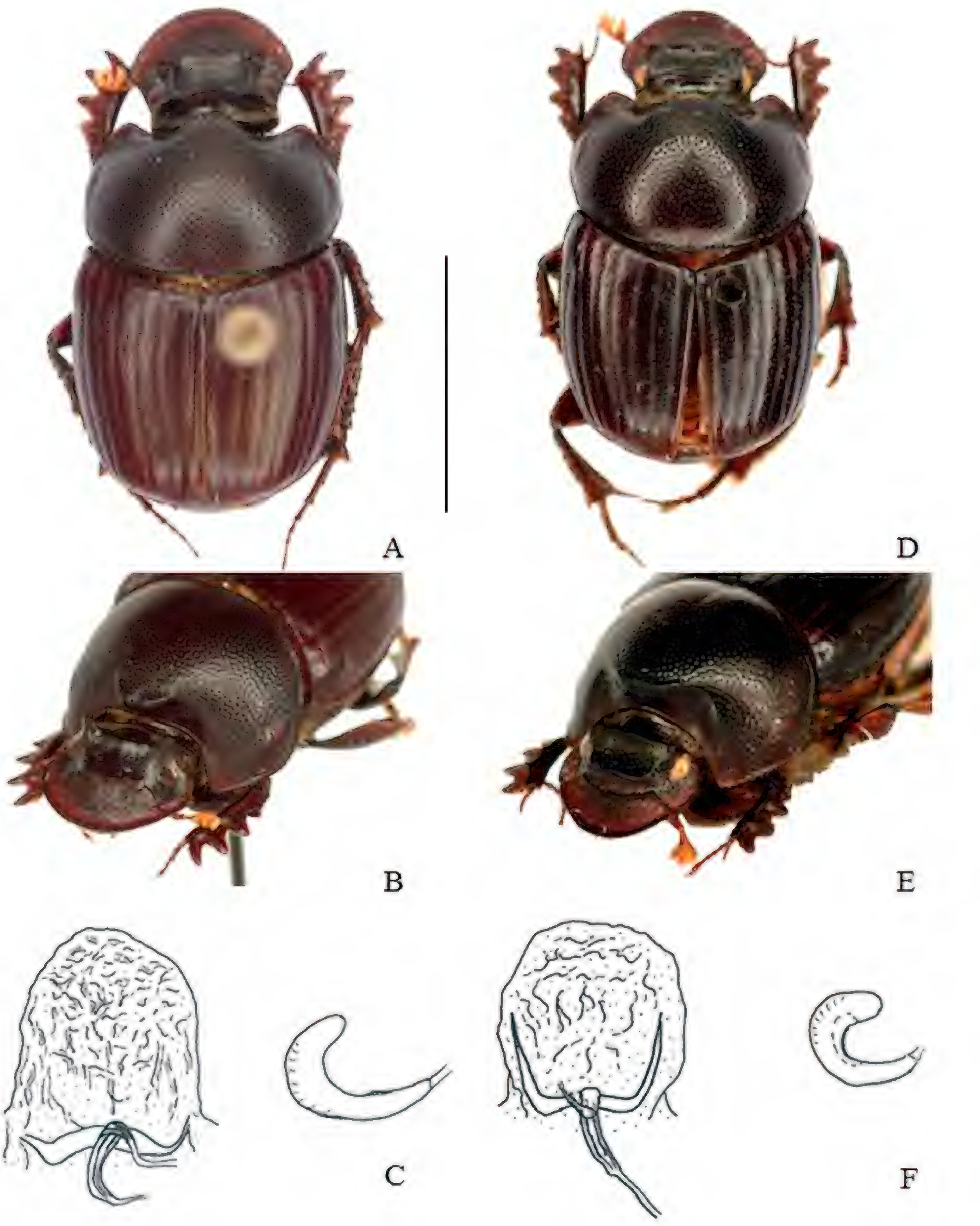


Fig. 5. A–C. *Onthophagus (Colobonthophagus) aenescens* (Wiedemann, 1823) ♀. **D–F** *Onthophagus (Colobonthophagus) urellus* Boucomont, 1920, paralectotype, ♀. **A, D**. Habitus, dorsal view. **B, E**. Habitus, fronto-ventral view. **C, F**. Vagina & spermathec. Scale = 5 mm.

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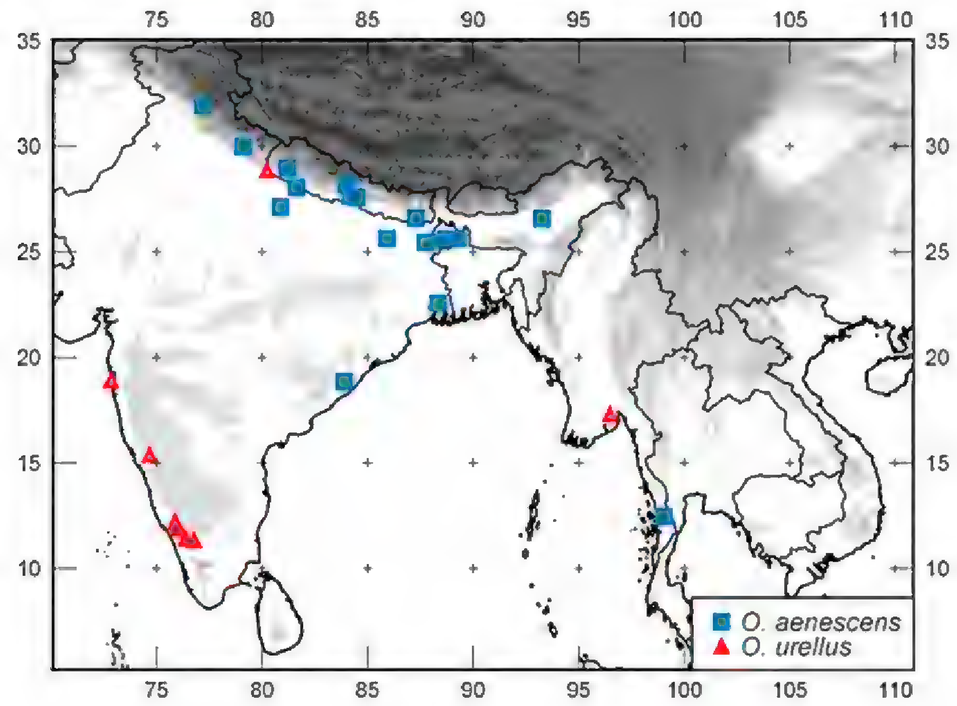


Fig. 6. Map. Blue square = *Onthophagus* (*Colobonthophagus*) *aenescens* (Wiedemann, 1823); red triangle = *Onthophagus* (*Colobonthophagus*) *urellus* Boucomont, 1920.

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Historical collection of snakes from Brazil by herpetologist and biogeographer Paul Müller (1940–2010), deposited at the Zoological Research Museum Alexander Koenig, Germany

Coleção histórica de serpentes do Brasil do herpetólogo e biogeógrafo Paul Müller (1940–2010), depositada no Zoological Research Museum Alexander Koenig, Alemanha

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Abstract. Natural history collections are constituted of a wide variety of biological specimens preserved around the world. They represent a continuous source of knowledge and play a fundamental role in the synthesis on the diversity, composition, distribution, and conservation of species. Paul Müller (1940–2010) was a German zoologist who collected amphibians and reptiles in Brazil between 1964 and 1976, with the aim of increasing knowledge about the Brazilian fauna and understanding the general patterns of Neotropical biogeography. We examined and re-determined all snakes found in Paul Müller's collection, deposited at the Zoological Research Museum Alexander Koenig (ZFMK), and also reconstructed the itinerary of his journeys through Brazil. We identified 556 snake specimens belonging to 80 species from six families (Aniliidae, Boidae, Colubridae, Dipsadidae, Elapidae, and Viperidae). Müller collected snake specimens from all regions of Brazil, although most are from the south (76% of the species) and southeast (14% of the species). This relevant material can contribute to historical, biogeographic and conservation studies of the Brazilian snake fauna.

Key words. Biodiversity, Reptilia, Serpentes, Southeast Brazil, South Brazil, Scientific Collections.

Resumo. As coleções de história natural são constituídas de uma grande variedade de espécimes biológicos preservados em todo mundo. Elas são fontes contínuas de novos conhecimentos e apresentam um papel fundamental na síntese sobre a diversidade, composição, distribuição e conservação das espécies. Paul Müller (1940–2010) foi um zoólogo alemão que coletou espécies de anfíbios e répteis no Brasil entre os anos de 1964 à 1976, com o intuito de aumentar o conhecimento sobre a fauna brasileira e entender os padrões gerais da biogeografia neotropical. Nós examinamos e re-determinamos todos os indivíduos encontrados na coleção de Paul Müller, depositada no Zoological Research Museum Alexander Koenig (ZFMK) e também recriamos o roteiro de suas viagens pelo Brasil. Nós identificamos 556 espécimes de serpentes de 80 espécies pertencentes a seis famílias (Aniliidae, Boidae, Colubridae, Dipsadidae, Elapidae and Viperidae). Müller coletou exemplares de serpentes de todas as regiões do Brasil, embora a maioria seja das regiões sul (76% das espécies) e sudeste (14 % das espécies). Este relevante material pode contribuir para estudos históricos, biogeográficos e conservacionistas da fauna de serpentes brasileiras.

Palavras-chave. Biodiversidade, Reptilia, Serpentes, Sudeste do Brasil, Sul do Brasil, Coleções científicas.

INTRODUCTION

Natural history collections are made up of a wide variety of biological specimens preserved around the world and their purpose is to document biodiversity and its distribution and to serve as a resource for research and education (Winker 2004). This set of specimens comprise an invaluable record of the evolution of life and is the basis

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for many biological researches such as taxonomy and systematics, ecology, biogeography, mapping and monitoring (Renner & Ricklefs 1994; O'Connell et al. 2004; Winker 2004; Pyke & Ehrlich 2010; Ballard et al. 2017).

Paul Müller (1940–2010) was a German zoologist who studied and collected amphibians and reptiles in Brazil from 1964 to 1976. His main interests were related to zoogeographical-ecological issues and problems of the evolutionary genetics of amphibians and reptiles of the Neotropics (Müller 1971). Müller visited different regions of Brazil and gathered a huge collection of vertebrates, including more than 6000 herpetological specimens (Monzel 2016). His research on the Neotropical herpetofauna focused on processes of differentiation of amphibians and reptiles on islands on the east coast of Brazil, such as the island of São Sebastião in São Paulo and the island of Santa Catarina (e.g., Müller 1968a, c, 1969b, c). Biogeographical studies on the island of São Sebastião resulted in his PhD thesis (see Müller 1968). In addition, his research on islands has resulted in a large number of new species distribution records (e.g., Müller 1968b, c, d, 1974, 1975, 1978). He also studied important Brazilian herpetological collections, such as the Museu Goeldi in Belém (Pará), the Museu Nacional in Rio de Janeiro, and the Instituto Butantan in São Paulo, where he collected data to obtain an overview of the morphological variability of the species he collected in the field (Monzel & Böhme 2010). Müller published in 1973 his famous work "Dispersal centres of terrestrial vertebrates in the Neotropic realm" (see Müller 1973), which was the result of his major field research from 1964 until 1970 and his investigations in Neotropical biogeography.

Throughout his research in Brazil, Paul Müller met important Brazilian herpetologists such as Paulo Emílio Vanzolini, Afrânio do Amaral, Alphonse Richard Hoge, Thales de Lema and Paulo Sawaya, the latter became a friend and, to some extent, his "Brazilian supervisor" (Monzel & Böhme 2010). On his return to Germany, Paul Müller took his collection of amphibians and reptiles to the University of Saarbrücken, where he was a professor and appointed head of the Institute of Biogeography in 1971, and later, in 1999, moved his collection to the University of Trier, where he accepted an offer to establish a new biogeographic institute (Monzel & Böhme 2010). After he retired in 2006, Paul Müller donated his important herpetological collection to the Zoological Research Museum Alexander Koenig, Germany (Monzel & Böhme 2010).

In this study, we have examined and re-determined all snake individuals found in Paul Müller's collection and also reconstructed Paul Müller's journey through Brazil over the years.

MATERIAL AND METHODS

We identified all snake specimens following the current nomenclature (e.g., Campbell & Lamar 2004; Grazziotin et al. 2012; Pyron et al. 2013; Hoogmoed et al. 2019). In addition, we recovered some of the material that was poorly preserved, changed all the containers that were damaged and renewed the alcohol. After having carefully analyzed all the samples, we inserted the museum label (ZFMK), but we also kept Paul Müller's original field labels. We then entered the field information of the specimens into the museum's database.

For the construction of the map with Paul Müller's travel itinerary through Brazil, we used the information of the location, and the date on which the snake specimens were collected. We georeferenced the points of the locations where Paul Müller collected the species, that is, in this process we considered only the snake specimens that were collected by him. Then, we inserted all the information in ArcGIS 10.1 (ESRI 2004) and built a map.

RESULTS

We identified 80 snake species distributed in 556 specimens and six families (Aniliidae, Boidae, Colubridae, Dipsadidae, Elapidae, and Viperidae) in Paul Müller's collection (Table 1, Fig. 1). The family Dipsadidae is the most represented in the collection, with the largest



Fig. 1. Paul Müller's Snake Collection deposited at the Zoological Research Museum Alexander Koenig, Germany. *Philodryas olfersii* Günther, 1885 (ZFMK 102104), collected in Rio Grande do Sul (A), snake specimens from the collection (B), *Bothrops alternatus* Duméril, Bibron & Duméril, 1854 (ZFMK 102119) collected in Rio Grande do Sul (C).

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Table 1. Number of specimens (N) of each snake species in Paul Müller's collection, the respective catalogue number of the Zoological Research Museum Alexander Koenig (ZFMK) and the location where the species was collected. The abbreviations in the localities column correspond to the following Brazilian states: AM (Amazonas), BA (Bahia), MG (Minas Gerais), MT (Mato Grosso), PA (Pará), RJ Rio de Janeiro, RS (Rio Grande do Sul), SC (Santa Catarina) and SP (São Paulo).

Family/Species	**N**	**(ZFMK)**	**Localities**
Aniliidae			
Anilius scytale (Linnaeus, 1758)	1	102325	AM: Manaus
Boidae			
Boa constrictor Linnaeus, 1758	10	091896; 096323-28; 096357-59	AM: Manaus, Careiro; PA: Santarém, Belém, Marituba, Ilha de Marajo
Epicrates crassus Cope, 1862	1	102405	MG: Pedro Leopoldo
Colubridae			
Chironius bicarinatus (Wied-Neuwied, 1820)	7	102129-34; 102453	RS: São Leopoldo; SP: Ilha de São Sebastião, São Sebastião
Chironius exoletus (Linnaeus, 1758)	6	102374; 102448; 102463; 102591-92; 102609	RS: São Leopoldo, SC: Florianópolis; Ecuador
Chironius fuscus (Linnaeus, 1758)	1	102607	Brazil
Chironius quadricarinatus Boie, 1827	1	102608	MT: Cuiabá
Drymarchon corais (Boie, 1827)	1	102407	RS: Taquari
Leptophis ahaetulla (Linnaeus, 1758)	2	102380-81	AM: Uaupés, Manaus
Palusophis bifossatus (Raddi, 1820)	2	102170; 102624	RS: São Leopoldo
Spilotes pullatus (Linnaeus, 1758)	3	102110; 102602-03	RS: São Leopoldo; SC: Florianópolis; SP: Ilha de São Sebastião
Spilotes sulphureus (Wagler, 1824)	2	102090-91	AM: Manaus
Dipsadidae			
Apostolepis assimilis (Reinhardt, 1861)	1	102120	SC: Florianópolis
Atractus paraguayensis Werner, 1924	5	102191; 102439-43	RS: Taquara; SC: Florianópolis
Atractus reticulatus (Boulenger, 1885)	2	102140-102534	RS: São Leopoldo
Cercophis auratus (Schlegel, 1837)	2	102484-85	SC: Florianópolis
Dipsas albifrons (Sauvage, 1884)	2	102510; 102517	SP: Ilha de São Sebastião
Dipsas indica Laurenti, 1768	1	102201	RS: São Leopoldo
Dipsas mikanii (Schlegel, 1837)	1	102458	RS: São Leopoldo
Dipsas neuwiedi (Ihering, 1911)	11	102660-69; 102671	SC: Ilha de Santa Catarina
Dipsas turgida Cope, 1868	6	102203-04; 102541; 102459; 102613-14	SC: Ilha de Santa Catarina; RS: Campo Bom, Morro Reuter, São Leopoldo
Dipsas ventrimaculatus (Boulenger, 1885)	18	102193; 102198; 102460-62; 102569-79; 102606; 102622	RS: Santa Cruz do Sul; São Leopoldo
Echinanthera cephalostriata Di Bernardo, 1996	2	102491-92	SP: Ilha de São Sebastião
Echinanthera cyanopleura (Cope, 1885)	5	102449; 102530; 102610; 102615; 102617	RS: Campo Bom, São Leopoldo, Taquara; SC: Florianópolis
Echinanthera melanostigma (Wagler, 1824)	1	102092	SP: Ilha de São Sebastião
Erythrolamprus aesculapii (Linnaeus, 1758)	2	102178; 102383	MT: Cuiabá; SP: São Sebastião
Erythrolamprus almadensis (Wagler, 1824)	9	102207; 102209; 102445; 102475; 102483; 102493-94; 102513; 102605	MT: Cuiabá, RS: São Leopoldo; SC: Florianópolis; SP: Ilha de São Sebastião
Erythrolamprus jaegeri (Günther, 1858)	9	102126; 102206; 102496; 102542-43; 102600; 102648; 102673-74	RS: São Leopoldo, Taquara

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Table 1. continued.

Family/Species	N	(ZFMK)	Localities
Erythrolamprus miliaris (Linnaeus, 1758)	35	102128; 102136; 102137-39; 102165-69; 102438; 102456-57; 102473-74; 102488-90;102535-39; 102580; 102594-99; 102626; 102675-76; 102682-83	RS: Campo Bom, São Francisco de Paula, São Leopoldo, Taquara; SC: Florianópolis; SP: Ilha de São Sebastião
Erythrolamprus poecilogyrus (Wied-Neuwied, 1825)	56	102187; 102189; 102199; 102200; 102205; 102350-51; 102379; 102436-37; 102447; 10245052; 10246467; 102477; 102482; 102486-87; 102514; 102524-29; 102544-48; 102618; 102625-28; 102640; 102649-58; 102677-80; 102684-87	MT: Cuiabá, PA: Marajó; RS: Balneário Pinhal, Campo Bom, São Leopoldo, Novo Hamburgo, Panambi, Passo Fundo, Portão, Porto Alegre, Santa Cruz do Sul, São Francisco de Paula, São Leopoldo, Taquara, Viamão, SC: Florianópolis
Erythrolamprus semiaureus (Cope, 1862)	3	102497-98; 102516	RS: São Leopoldo, São Sebastião do Caí
Erythrolamprus typhlus (Linnaeus, 1758)	1	102320	RS: Taquara
Helicops carinicaudus (Wied-Neuwied, 1825)	16	102153-58; 102384; 102469; 102499; 102500; 102504-58; 102561	RS: São Leopoldo
Helicops infrataeniatus Jan, 1865	27	102159-64; 102501-09; 102515; 102559; 102612; 102616; 102630	RS: Campo Bom, Porto Alegre, São Leopoldo
Lygophis anomalus (Günther, 1858)	2	102152; 102468	RS: São Leopoldo, SC: Ilha de Santa Catarina
Lygophis flavifrenatus Cope, 1862	2	102481; 102672	RS: Passo Fundo, Viamão
Lygophis lineatus (Linnaeus, 1758)	4	102551-54	PA: Marajó
Oxyrhopus clathratus Duméril, Bibron & Duméril, 1854	6	102478-83	RS: São Leopoldo
Oxyrhopus formosus (Wied-Neuwied, 1820)	1	102633	AM: Manaus
Oxyrhopus guibei Hoge & Romano, 1977	1	102173	RS: São Sebastião do Caí
Oxyrhopus petolarius (Linnaeus, 1758)	1	102202	SP: São Sebastião
Oxyrhopus rhombifer Duméril, Bibron & Duméril, 1854	12	102143-51; 102195-97	RS: Morro Reuter, Novo Hamburgo, Santa Cruz do Sul, São Leopoldo
Phalotris lemniscatus (Duméril, Bibron & Duméril, 1854)	1	102194	RS: São Leopoldo
Phalotris reticulatus (Peters, 1860)	1	102639	RS: São Leopoldo
Philodryas aestiva (Duméril, Bibron & Duméril, 1854)	12	102121; 102122; 102171; 102179; 102454; 102471; 102495; 102587-90; 102643	RS: São Leopoldo, SC: Florianópolis, Ilha de Santa Catarina, SP: Ilha de São Sebastião
Philodryas argentea (Daudin, 1803)	3	102406; 102619-20	AM: Manaus; Ecuador
Philodryas olfersii (Lichtenstein, 1823)	19	102093-99; 102104; 102109; 102172; 102180; 102442; 102455; 102470; 102480; 102549; 102550; 102644; 102647	SC: Ilha de Santa Catarina; RS: General Câmara, Morro Reuter, Panambi, Portão, Santa Cruz do Sul, São Leopoldo, Taquara
Philodryas patagoniensis (Girard, 1858)	9	102135; 102446; 102472; 102476; 102547; 102611; 102631-32; 102670	RS: Passo Fundo, São Leopoldo, SC: Florianópolis; SP: Ilha de São Sebastião, São Sebastião
Pseudoboa haasi (Boettger, 1905)	1	102208	RS: São Leopoldo
Pseudoboa neuwiedii (Duméril, Bibron & Duméril, 1854)	1	102531	AM: Manaus
Siphlophis pulcher (Raddi, 1820)	1	102638	SC: Florianópolis

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Table 1. continued.

Family / Species	N	(ZFMK)	**Localities**
Taeniophallus bilineatus (Fischer, 1885)	2	102601; 102645	SC: Ilha de Santa Catarina; SP: Ilha de São Sebastião
Thamnodynastes sp.	1	102681	RS: São Leopoldo
Thamnodynastes nattereri (Mikan, 1828)	9	102182-86; 102511-12; 102532; 102584	SP: Ilha de São Sebastião
Thamnodynastes hypoconia (Cope, 1860)	1	102192	SP: Ilha de São Sebastião
Thamnodynastes lanei Bailey, Thomas & Silva-Jr, 2005	1	102533	PA: Ilha de Marajó
Tomodon sp.	1	102659	RS: Taquara
Tropidodryas serra (Schlegel, 1837)	3	102117; 102634-35	SC: Florianópolis
Tropidodryas striaticeps (Cope, 1870)	1	102636	SC: Florianópolis
Xenodon dorbignyi (Bibron, 1854)	13	102174-77; 102518-23; 102540; 102593; 102637	RS: Campo Bom, Praia da Pinhal, São Leopoldo; SC: Florianópolis; SP: Ilha de São Sebastião
Xenodon matogrossensis (Scrocchi & Cruz, 1993)	1	102604	MT: Rondonópolis
Xenodon merremii (Wagler, 1824)	26	102101-07; 102333-36; 102382; 102391-04; 102444	RS: Santa Cruz do Sul, São Francisco de Paula, São Leopoldo, Taquara
Xenodon neuwiedii Günther, 1863	4	102123; 102127; 102181; 102646	RS: Morro Reuter, São Leopoldo; SC: Florianópolis, Ilha de Santa Catarina
Elapidae			
Micrurus altirostris (Cope, 1860)	18	096392-01; 102111-15; 102188; 102190; 102621	RS: Campo Bom, Portão, Santa Cruz do Sul, São Leopoldo
Micrurus averyi Schmidt, 1939	1	102629	AM: Manaus
Micrurus corallinus (Merrem, 1820)	30	102141; 102387-90; 102408-32	SC: Florianópolis; SP: Ilha de São Sebastião
Micrurus frontalis Duméril, Bibron & Duméril, 1854	3	102386; 102623; 102108	MT: Cuiabá; SP: São Sebastião
Micrurus spixii Wagler, 1824	1		AM: Manaus
Viperidae			
Bothrops alternatus Duméril, Bibron & Duméril, 1854	9	102119; 102319; 102329; 102338-39; 102341; 102346; 102355; 102372	RS: Portão, São Leopoldo; SP: São Sebastião
Bothrops atrox (Linnaeus, 1758)	2	102142	AM: Manaus
Bothrops bilineatus (Wied-Neuwied, 1821)	1	102378	Ecuador: Quito
Bothrops cotiara (Gomes, 1913)	3	102118; 102310-11	RS: São Leopoldo
Bothrops diporus Cope, 1862	3	102124; 102125; 102344	RS: Erval seco, Portão
Bothrops insularis (Amaral, 1921)	1	93234	SP: Ilha de Queimada Grande
Bothrops jararaca (Wied-Neuwied, 1824)	65	32540; 102100; 102321-24; 102337; 102342; 102345; 102347; 102352-54; 102356-60; 102362-71; 102377; 102433-35; 102688-99	RJ: Rio de Janeiro; RS: São Leopoldo; SC: Florianópolis; SP: Ilha de São Sebastião, São Sebastião; Ecuador: Quito
Bothrops jararacussu Lacerda, 1884	3	102326; 102327; 102373	SP:Ilha de São Sebastião
Bothrops leucurus Wagler, 1824	1	102116	BA: Costa Oeste da Bahia
Bothrops moojeni Hoge, 1966	2	102328; 102343	MG: Pedro Leopoldo
Bothrops pubescens (Cope, 1870)	14	102312-18; 102330-32; 102340; 102348-49; 102361	RS: Panambi, Portão, São Leopoldo
Crotalus durissus Linnaeus, 1758	7	093229-33; 102375-76	MG: Belo Horizonte; RS: São Leopoldo; SP: Campinas

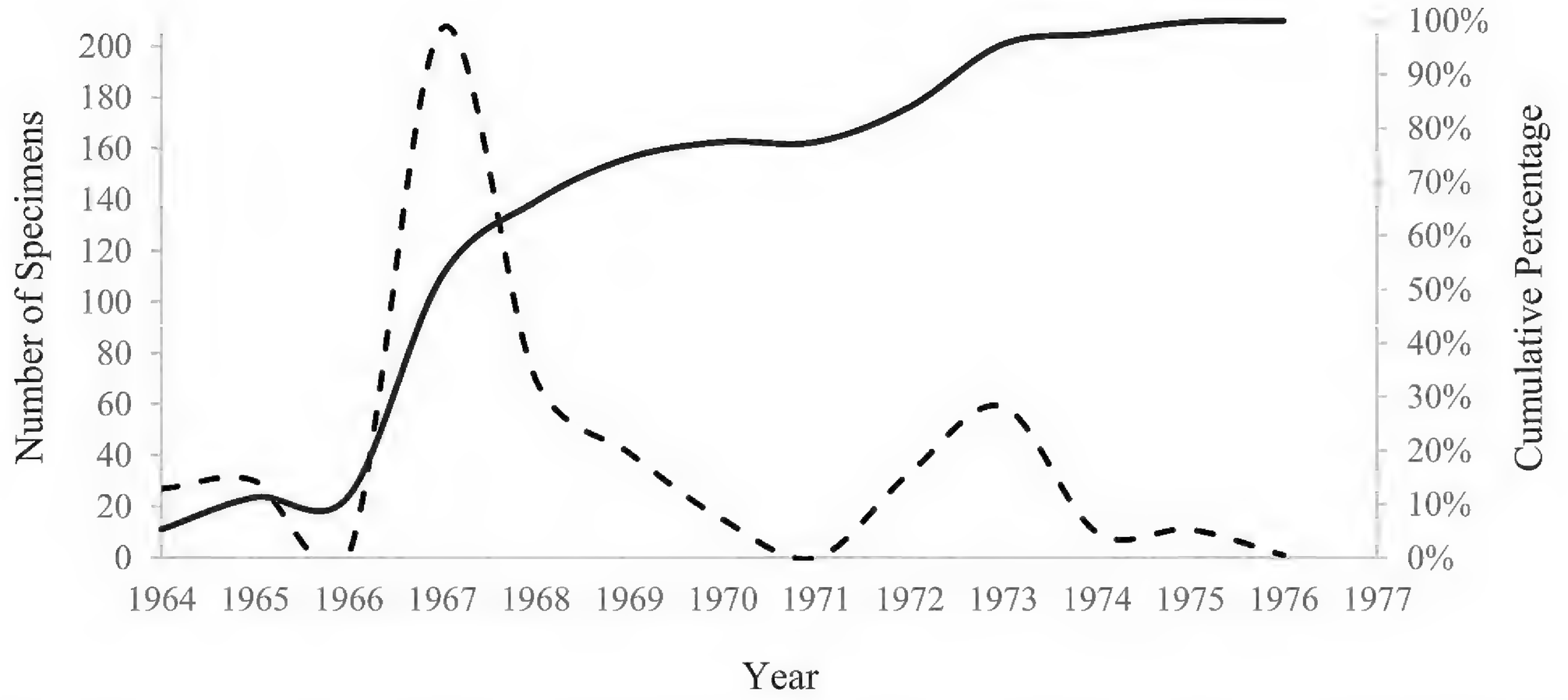


Fig. 2. Number of specimens collected per year (dotted line) and the cumulative percentage of specimens from Paul Müller's collection between 1964 and 1976 (non-dotted line).

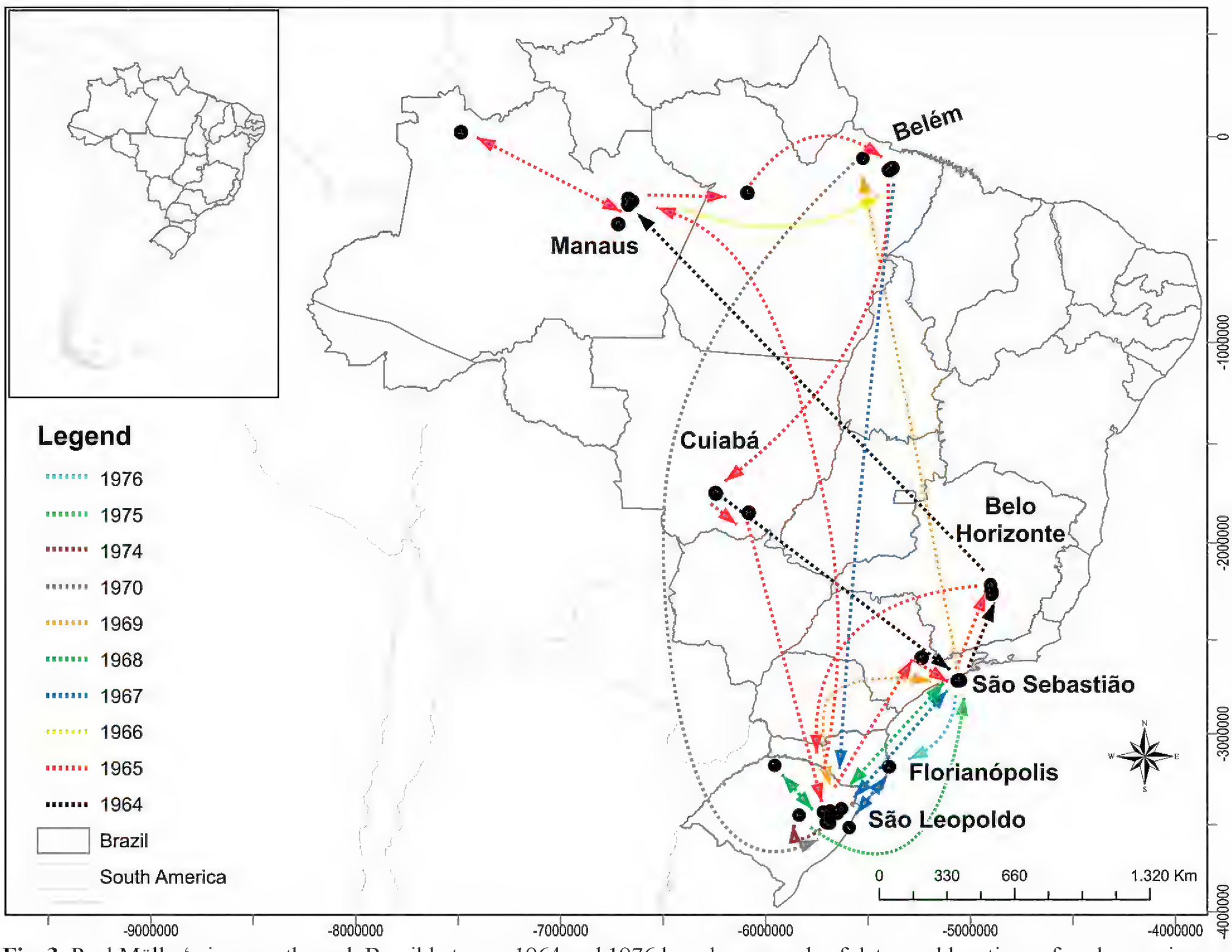


Fig. 3. Paul Müller's journey through Brazil between 1964 and 1976 based on records of dates and locations of snake specimens. The color of the dotted lines represents the year of the journey and the arrow indicates the direction of movement throughout the year.



Fig. 4. Number of snake specimens from Paul Müller's collection collected in nine Brazilian states (Amazonas, Bahia, Minas Gerais, Mato Grosso, Pará, Rio de Janeiro, Rio Grande do Sul, Santa Catarina and São Paulo).

number of species (50 spp.) and specimens (N = 357), followed by the family Viperidae, with 12 species and 109 specimens. *Bothrops jararaca* (N = 65) and *Erythrolamprus poecilogyrus* (N = 56) are the species with the highest number of specimens in the collection.

Most of the specimens (86%) were collected in Brazil between 1964 and 1976 (Fig. 2). During this period, Paul Müller made several herpetological expeditions to different states of the country (Fig. 3). However, Paul Müller did not collect all specimens himself, 29% of the specimens were collected by collaborators. In the collection, there are five specimens of the genus *Bothrops* (*B. jararaca*, *B. leucurus*, *B. insularis*, *B. cotiara*, and *B. pubescens*) collected in Brazil, between 1909 and 1963, which were donations, as well as five other specimens (*Bothrops bilineatus, Bothrops jararaca, Chironius exoletus*, and *Philodryas argentea* (N = 2) which are from Ecuador.

In Paul Müller's collection there are snake specimens from all regions of Brazil, although most are from the south (N = 422; 76%) and southeast (N = 81; 14%). Most of the specimens in the collection were captured in the state of Rio Grande do Sul (53%), in the municipalities of São Leopoldo, Campo Bom, Portão and Taquara, in the state of Santa Catarina (22%), on the island of Santa Catarina, and in the state of São Paulo (13%), on the island of São Sebastião (Fig. 4). There is only one specimen from the Northeast region, a *Bothrops leucurus* collected in Bahia in 1912 which was donated to the collection.

DISCUSSION

Paul Müller's first expeditions to Brazil were aimed at obtaining as much information as possible about the vertebrate fauna and butterflies from all over the country and thus increasing knowledge about the diversity of the fauna and inferring patterns from Neotropical biogeography (Müller 1971; Monzel & Böhme 2010). According to Müller (1971), Brazil is of extreme zoogeographical interest, since it is the largest country in South America, with a tropical climate and a much differentiated vegetation zoning. It presents a transition between the humid forests of Ecuador, Colombia and Guyanas, on the one hand, and the dry areas of the Argentinean Pampa and Paraguay, on the other. Although Müller had a vast knowledge of several groups of animals, most of his studies were in the area of herpetology (Monzel & Böhme 2010).

During his expeditions to Brazil, Müller visited several states, but concentrated his collections on the Brazilian coastal states, mainly Rio Grande do Sul, São Paulo and Santa Catarina. Of these, Rio Grande do Sul was the state with the largest number of snake specimens collected. Although the focus of Paul Müller's work in Brazil was on island fauna (e.g., Müller 1968a, b, c, 1969a, b, c), most of the collection sites in Rio Grande do Sul are not islands. The number of specimens collected both in Rio Grande do Sul and Santa Catarina is also due to the help of Paul Müller's friends, who supported him in collecting the specimens and whom he thanked in his work, namely Erno Böhler and Flavio Silva (both from São Leopoldo) and Canisius Ritter (Florianópolis) (e.g., Müller 1968c, 1971).

The most numerous species in Paul Müller's collection were *Bothrops jararaca* and *Erythrolamprus poecilogyrus*. *B. jararaca* is a species widely distributed in the South and Southeast of Brazil (Sazima 1992; Grazziotin et al. 2006; Monzel & Wüster 2008) and common in the Serra do Mar region (Centeno et al. 2008). *E. poecilogyrus* is common and widely distributed throughout Brazil (Dixon & Markezich 1992; Alencar & Nascimento 2014). No species registered in Paul Müller's collection is in the threatened species category of the Brazilian red list of threatened species, except *B. insularis,* which is Critically Endangered (ICMBio 2018). Among the snakes in the collection are two specimens of *Uromacerina ricardinii*, used by Paull Müller to report the first record of the species for the state of Santa Catarina (see Müller 1978). Recently the species underwent a synonymization process and today it is known as *Cercophis auratus* (Hoogmoed et al. 2019).

In the collection, there are some species that provide information from interesting collection locations. For example, there are two specimens of *Dipsas turgidus* collected in Florianópolis, Santa Catarina. In Brazil, the distribution of *D. turgidus* covers the states of Mato Grosso, Minas Gerais, Rio de Janeiro, Rio Grande do Sul and São Paulo (Wallach et al. 2014). There are four individuals of *Xenodon dorbignyi* from São Sebastião Island, in São Paulo. This species has a known distribution in the extreme south of Brazil, Uruguay, southern Paraguay and central-northern Argentina (Orejas-Miranda 1966; Giraudo 2001; Nenda & Cacivio 2007; Kunz et al. 2011; Cacciali et al. 2016). In addition, other species with location information for São Sebastião and São Sebastião Island, in São Paulo, have not yet been registered in these locations. For example, *B. alternatus* (N = 4), *Micrurus frontalis* (N = 1) and *Oxyrhopus petolarius* (N = 1) col-

lected in São Sebastião, and the species *Philodryas aestiva* (N = 1), *Echinanthera melanostigma* (N = 1) and *Erythrolamprus almadensis* (N = 1) collected on São Sebastião Island (see Cicchi et al. 2007; Centeno et al. 2008). The absence of records of these species for these locations can be explained by a variety of factors, such as the rarity of some species in the region or the preference of habitats of some species. Errors may have occurred in the records of the collection locations of these species or even some of these species may have disappeared from these locations due to changes in land use in recent decades.

The analysis of snake specimens from Paul Müller's collection can contribute to historical biogeographic and conservationist studies of the Brazilian snake fauna. In addition, given the current scenario of material loss caused by recent incidents in large Brazilian collections, such as the fires at the Instituto Butantan in 2010 and the Museu Nacional in 2018 (see Mega 2019), these collections can provide valuable information and help to soften the impact of material loss.

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Tree-fungus beetles collected on sawdust substrate with mycelium of selected fungal species on trees at the Experimental Forest Station in Rogów (central Poland)

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Abstract. This study of beetles attracted by a sawdust substrate overgrown with mycelium of rare species of wood-decay fungi was aimed to assess (1) ecological groups of the beetles caught in traps with such a substrate; (2) species composition of beetle communities attracted to sawdust substrate with the selected wood-decay fungi. To determine which tree-fungus beetles are associated with selected species of wood-decay fungi, we caught beetles in traps with sawdust substrate overgrown by the mycelium of seven species of wood-decay fungi: *Bondarzewia mesenterica* (Schaeff.) Kreisel, *Fistulina hepatica* (Schaeff.) With., *Fomitopsis rosea* (Alb. & Schwein.) P. Karst., *Grifola frondosa* (Dicks.) Gray, *Hericium alpestre* Pers., *H. coralloides* (Scop.) Pers. and *Meripilus giganteus* (Pers.) P. Karst. The research was carried out in central Poland, at the Forest Experimental Station in Rogów. One research season (April–October) yielded a total catch of 133 beetle species associated with wood-decay fungi, including 60 mycetobiontic species. The most abundant species of beetles were: *Trixagus carinifrons* (Bonvouloir, 1859), *Cortinicara gibbosa* (Herbst, 1793), *Dienerella ruficollis* (Marsham, 1802), *Rhizophagus bipustulatus* (Fabricius, 1792), and *Aulonothroscus brevicollis* (Bonvouloir, 1859). Two autonomous clusters of tree-fungus beetles were distinguished in the collected material: beetles associated with brown rot and beetles associated with white rot. The sawdust substrates with mycelium of wood-decay fungi, used in traps, attract mycetophilic and mycetobiontic beetles.

Key words. Coleoptera, mycetophilic beetles, mycetobiontic beetles, wood-decay fungi, Poland.

INTRODUCTION

The largest taxonomic group of animals that live in and on fungi are insects, mostly beetles. This group of organisms plays a major role in decomposition of tree fungi (Gilbertson 1984). Many fruiting bodies of wood-decay fungi are very attractive food for beetles, which feed also on the mycelium that penetrates wood (Benick 1952; Hammond & Lawrence 1989; Butin 1995; Pecci-Maddalena & Lopes-Andrade 2017). Some beetles are highly specific and associated only with a single fungal species. For example, bark beetles (Curculionidae: Scolytinae) live in symbioses with primarily ophiostomatoid Ascomycetes (Linnakoski et al. 2012; Six 2012).

However, little is known about beetles associated with rare wood-decay fungi because of their limited area of distribution (usually in natural or nearly natural forests), short period of occurrence of fruiting bodies, and their quick decomposition. Apart from the fruiting bodies of fungi that are commonly found on trees, such as *Fomes fomentarius* (L.) Fr., *Fomitopsis pinicola* (Sw.) P. Karst. or *Trametes* spp., also fruiting bodies of protected species are visited by many beetle species. Poland was the first country in Europe to introduce fungal species protection, in 1983 (Ordinance 1983). Since 2014, 54 species of macrofungi are strictly protected, while 63 are partly protected, so in total 117 fungal species are protected in Poland, including 20 wood-decay fungi (Ordinance 2014). A majority of the protected wood-decay fungi are associated mostly with primeval forests. Such habitats are located primarily in national parks and nature reserves, i.e., in areas where large amounts of dead wood lie on the forest floor. Creation of suitable conditions for development of wood-decay fungi by leaving dead wood or stopping timber harvesting in forests does not mean that valuable, rare species will immediately appear there. The natural process of wood colonization by fungi takes many years, and production of fruiting bodies is only one of the final stages of mycelium development in wood.

Among beetles of wood-decay and other tree fungi, some are mycetobiontic (obligatorily associated with fungi), while others are mycetophilic (facultatively as-

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sociated with fungi). According to published data, the following mycetobiontic beetles have been recorded on 7 species of wood-decay fungi (six species protected in Poland) selected for this study:

– on *Fistulina hepatica* (Schaeff.) With.: *Cryptophagus pubescens* Sturm, 1845, *C. scanicus* (Linnaeus, 1758), *Micrambe abietis* (Paykull, 1798), *Dacne bipustulata* (Thunberg, 1781), *Mycetophagus piceus* (Fabricius, 1777), *Psudotriphyllus suturalis* (Fabricius, 1801), *Triphyllus bicolor* (Fabricius, 1777), *Abdera flexuosa* (Paykull, 1799), *Orchesia micans* (Panzer, 1793) (Benick 1952; Burakowski et al. 1986, 1987; Nikitsky 1993; Nikitsky & Schigel 2004; Borowski 2006),
– on *Fomitopsis rosea* (Alb. & Schwein.) P. Karst.: *Agaricochara latissima* (Stephens, 1832), *Dolichocis laricinus* (Mellié, 1848), *Cis dentatus* Mellié, 1848, *C. glabratus* Mellié, 1848, *Ennearthron cornutum* (Gyllenhal, 1827) (Scheerpeltz & Höfler 1948; Krasutsky 1995, 1997),
– on *Grifola frondosa* (Dicks.) Gray: *Sepedophilus testaceus* (Fabricius, 1793) (Schigel 2007),
– on *Hericium coralloides* (Scop.) Pers.: *Scaphisoma agaricinum*, *Mycetophagus decempunctatus* Fabricius 1801, *M. multipunctatus* Fabricius, 1792, *M. quadriguttatus* Müller, 1821 (Benick 1952; Nikitsky 1993),
– on *Meripilus giganteus* (Pers.) P. Karst.: *Scaphisoma agaricinum* (Linnaeus, 1758), *Cryptophagus dentatus* (Herbst, 1793), *C. uncinatus* Stephens, 1830, *Cartodere nodifer* (Westwood, 1839), *Cortinicara gibbosa* (Herbst, 1793), *Cis micans* (Fabricius, 1792), *Orchesia micans* (Scheerpeltz & Höfler 1948; Benick 1952; Burakowski et al. 1987).

On the remaining two species of wood-decay fungi used in this study, i.e., *Bondarzewia mesentrica* (Schaeff.) Kreisel and *Hericium alpestre* Pers., no mycetobiontic beetles have been reported in the literature so far.

This study of beetles attracted by a sawdust substrate overgrown with mycelium of rare species of wood-decay fungi was aimed to assess (1) ecological groups of the beetles caught in traps with such a substrate; (2) species composition of beetle communities attracted to sawdust substrate with the selected wood-decay fungi.

MATERIAL AND METHODS

Study area

The study was conducted in 2008 in the arboretum of the Experimental Forest Station in Rogów (central Poland) (Fig. 1). The arboretum was created in 1925 in a forest and was associated since the very beginning with forest research. The arboretum now covers 53.76 ha, including 41 ha being open to visitors (Pewniak et al. 2004), but the research plot was established in the part that is closed to visitors. The plot is located in a modified low-lying oak-hornbeam forest *Tilio-Carpinetum stachyetosum*. It is dominated by *Pinus sylvestris* L. (aged about 130 years) and *Quercus robur* L. and *Quercus petraea* (Matt.) Liebl. (aged 100–200 years), with admixture of *Larix decidua* Mill., *Carpinus betulus* L., *Abies alba* Mill., *Betula pendula* Roth., and *Picea abies* (L.) H. Karst. The well-developed herb layer includes *Stellaria holostea* L., *Anemone nemorosa* L., *Galeobdolon luteum* Huds., *Deschampsia caespitosa* (L.) P. Beauv., *Poa trivialis* L., and *Rubus* spp.

The woodlands at Rogów are composed of small forest patches, covering less than 10 km^2. Moreover, the forest patches are clearly separated from one another and form a mosaic of small forest islands surrounded by farmland, characteristic of central Poland. They are poor in typical forest beetle species. However, the insect fauna of the Experimental Forest Station in Rogów is well studied, especially forest beetles (Borowski 2001).

Trapping

In the experiment, we used modified window traps designed by Økland (1996). A trap was made of two 20 × 30 cm Plexiglas plates crossing each other, a funnel and a preservative-filled bottle (ethylene glycol), and bait (sawdust substrate overgrown with mycelium) (Fig. 2). In the experiment we used mycelium of seven species of wood-decay fungi belonging to the division Basidiomycota, two of them causing brown rot: *Fistulina hepatica* (Schaeff.) With. and *Fomitopsis rosea*; and five causing white rot: *Bondarzewia mesenterica*, *Grifola frondosa*, *Hericium coralloides*, *H. alpestre*, and *Meripilus giganteus* (Table 1). Pure cultures of the fungi used to prepare the bait substrate originated from the collection of the Department of Forest Phytopathology and Mycology, Warsaw University of Life Sciences (SGGW). Identity of the mycelium was confirmed using molecular techniques, on the basis of the internal transcribed spacer (ITS) region of nuclear ribosomal DNA, which is used most often for research on genetic diversity of fungi (Seifert 2009). The analyses were performed at the laboratory of the Institute of Botany, Polish Academy of Sciences, Krakow.

The bait substrate was prepared by mixing and watering of sawdust of an appropriate tree species with ground wheat grain and inoculating it with mycelium. Beech sawdust (*Fagus sylvatica* L.) was prepared for *G. frondosa*, *H. coralloides*, and *M. giganteus*, fir sawdust (*Abies alba*) for *B. mesenterica* and *H. alpestre*, spruce sawdust (*Picea abies*) for *F. rosea*, and oak sawdust (*Quercus robur*) for *F. hepatica*. Each autoclavable polypropylene biohazard bag (7" × 12", Cole-Parmer, US) was filled with 180 g of the substrate (150 g of sawdust of the appropriate tree species and 30 g of ground wheat grain). The components were thoroughly mixed with 180 ml of distilled water. The initial moisture content of the substrate was about 100%. The bags were placed in an autoclave and sterilized at 121°C for 2 h, next moved to a

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Table 1. Characteristics of the fungi used to prepare the substrate attracting beetles (type of rot and major host plants according to: Kotlaba (1984), Kreisel (1987), Ryvarden & Gilbertson (1993, 1994), Wojewoda (2003)).

Species	Family	Rot type	Protection status in Poland	Major host plants
Bondarzewia mesenterica	Bondarzewiaceae	white	partial protection	*Abies*, *Picea*
Fistulina hepatica	Fistulinaceae	brown	partial protection	*Quercus*, *Castanea*
Fomitopsis rosea	Fomitopsidaceae	brown	partial protection	*Picea*, *Abies*
Grifola frondosa	Fomitopsidaceae	white	partial protection	*Quercus*, *Acer*, *Betula*, *Carpinus*, *Fagus*
Hericium alpestre	Hericiaceae	white	partial protection	*Abies*, *Picea*
Hericium coralloides	Hericiaceae	white	partial protection	*Fagus*
Meripilus giganteus	Meripilaceae	white	not protected	*Quercus*, *Fagus*, *Acer*, *Aesculus*

laminar air flow cabinet and left for a few hours, until they cooled down. The substrate was then inoculated with mycelium of an appropriate species (from cultures on Petri dishes), the bag was plugged with a cotton wool ball, and the neck of the bag was tightly wrapped in a colourless tape. The cotton wool was a filter that ensured gas exchange and simultaneously protected the substrate against microorganisms from the environment. Next the bags were kept for 8–10 weeks at 22°C in a Q-Cell 700 incubator, until the substrate was overgrown by mycelium, and then used in an experiment.

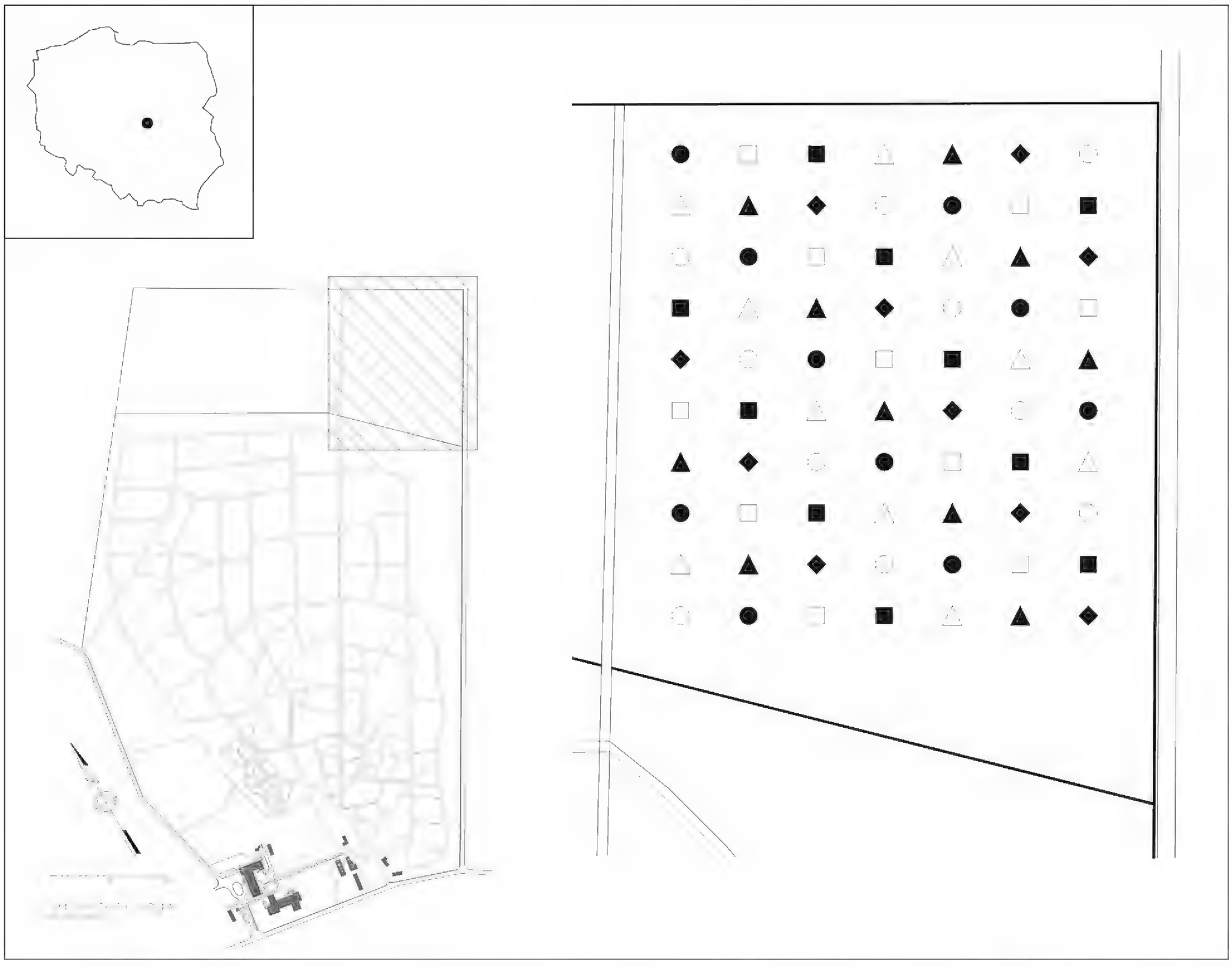


Fig. 1. Location of the study area and a scheme of distribution of the traps with mycelium of wood-decay fungi on sawdust substrate in the forest arboretum in Rogów. Symbols: ● = traps with *Bondarzewia mesentrica*; ○ = *Grifola frondosa*; ■ = *Fomitopsis rosea*; □ = *Meripilus giganteus*; ▲ = *Hericium coralloides*; Δ = *Hericium alpestre*; ◆ = *Fistulina hepatica*.



Fig. 2. Trap with mycelium of wood-decay fungi on sawdust substrate, used to catch beetles (photo J. Piętka).

Then, small pieces of the polypropylene film were cut off (at the top and at the bottom), and the substrate was mounted above a window trap hung on a tree. The traps were hanged at a height of 2 m, on young trees without injuries, to make sure that the caught insects were attracted by the substrate, rather than by a dying tree. From April to October in the study area 70 such bait traps were used, 10 for each of the studied species of wood-decay fungi. Once a month, the caught material was collected, transported to the laboratory, and next sorted and identified. The taxonomic classification and names of the identified insects follow the *Catalogue of Palearctic Coleoptera* (Löbl & Smetana 2003–2013). When analysing their dominance structure, Kasprzak & Niedbała's (1981) scale was used: superdominants (>30.00%), dominants (5.01–30.00%), subdominants (1.01–5.00%), and accidentals (≤1.00%). The faunistic similarity of tree beetle communities caught in traps with mycelium of individual species of wood-decay fungi on sawdust substrate was analysed using numerical cluster analysis. This analysis was based on the species composition (presence/absence of species). To distinguish between groups, Ward's algorithm was used, and squared Euclidean distance was a measure of similarity. Additionally, the faunistic similarity of tree-fungus beetle communities was analysed using Nonmetric Multidimensional Scaling (NMDS). Data on number of individuals were subjected to Hellinger transformation and NMDS based on Bray-Curtis similarity index. NMDS stress 0.099.

Results

From April to October 2008, we caught 2038 beetles of 133 species, representing 35 families (Table 2). In the collected material, the families represented by the largest numbers of species were the Latridiidae (11.3% of the total number of species), Staphylinidae (9.0%), Ciidae (6.0%), Cryptophagidae (6.0%), Curculionidae, Melandryidae, and Mycetophagidae (5.3% each). The families represented by the largest numbers of individuals were the Throscidae (23.6%), Latridiidae (19.6%), Monotomidae (7.6%), Cryptophagidae (7.0%), Salpingidae (6.6%), and Leiodidae (5.5%). The most abundant species were: *Trixagus carinifrons* (14.9%), *Cortinicara gibbosa* (7.1%), *Dienerella ruficollis* (7.1%), *Rhizophagus bipustulatus* (6.9%), and *Aulonothroscus brevicollis* (5,5%). These species and 15 others (*Acalles camelus*, *Agathidium nigripenne*, *A. seminulum*, *Anaspis frontalis*, *A. rufilabris*, *Cerylon histeroides*, *Cryptophagus dentatus*, *C. dorsalis*, *Dacne bipustulata*, *Ennearthron palmi*, *Litargus connexus*, *Mycetophagus multipunctatus*, *Salpingus planirostris*, *S. ruficollis*, and *Trixagus dermestoides*) were caught on all types of bait. On the other hand, 35 species were recorded only with one of the seven variants of the bait, and only three of them were caught in the number of more than one individual, i.e., *Hemicoelus canaliculatus* (two individuals in one trap with *Grifola frondosa* mycelium), *Dendrophilus punctatus* (two individuals in two traps with *Hericium alpestre* mycelium) and *Cis festivus* (three individuals in two traps with *Meripilus giganteus* mycelium).

Among biotope groups of beetles, the major contributors to the total number of species were the organisms associated with mycelium and fruiting bodies of fungi (mycetocoles – 48.1%) (Table 3). The most abundant among them were: *Trixagus carinifrons, Cortinicara gibbosa, Dienerella ruficollis*, and *Aulonothroscus brevicollis*. The second most species-rich biotope group is associated with partly or completely dead wood (saproxylocoles – 24.1%), represented most abundantly by *Anaspis rufilabris* and *Melasis buprestoides*. Corticoles were another relatively large group (17.3%), and the most abundant among them were *Rhizophagus bipustulatus*, *Salpingus ruficollis*, and *S. planirostris*.

Among the trophic groups (Table 4), mycetophagous (fungivorous) beetles were the most numerous (46.6% of the total number of species), and the most abundant species of this group were *Dienerella ruficollis*, *Cortinicara gibbosa*, and *Trixagus carinifrons*. Zoophages ranked second (24.1%), and saproxylophages ranked

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Table 2. List of beetles (Coleoptera) caught in traps with mycelium of wood-decay fungi on sawdust substrate in the arboretum in Rogów (central Poland) in 2008. Abbreviations: S = saproxylocoles; C = corticoles; M = mycetocoles; MY = myxomycetocoles; MI = myrmetocoles; sx = saproxylophages; z = zoophages; m = mycetophages; my = myxomycophages.

Family / Species	**Biotope groups**	**Trophic groups**	***Bondarzewia mesenterica***	***Fistulina hepatica***	***Fomitopsis rosea***	***Grifola frondosa***	***Hericium alpestre***	***Hericium coralloides***	***Meripilus giganteus***
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Anthribidae									
Dissoleucas niveirostris (Fabricius, 1798)	S	sx					1	1	
Pseudeuparius sepicola (Fabricius, 1792)	S	sx		1	1				
Platystomos albinus (Linnaeus, 1758)	S	sx			1				
Rhaphitropis marchica (Herbst, 1797)	S	sx							1
Cerambycidae									
Alosterna tabacicolor (DeGeer, 1775)	S	sx		1		1			
Grammoptera ruficornis (Fabricius, 1781)	S	sx	1						
Cerylonidae									
Cerylon ferrugineum Stephens, 1830	C	z		2	4	1	3		1
Cerylon histeroides (Fabricius, 1792)	C	z	2	8	5	4	11	4	4
Ciidae									
Cis boleti (Scopoli, 1763)	M	m		1	1	3			
Cis fagi Waltl, 1839	M	m			1				
Cis festivus (Panzer, 1793)	M	m							3
Cis micans (Fabricius, 1792)	M	m	2				1		
Ennearthron cornutum (Gyllenhal, 1827)	M	m		1	3	5	2	7	2
Ennearthron palmi Lohse, 1966	M	m	11	1	3	2	4	3	1
Octotemnus glabriculus (Gyllenhal, 1827)	M	m				1			
Orthocis pseudolinearis (Lohse, 1965)	M	m			2	1	1	3	1
Corylophidae									
Clypastraea brunnea (Brisout de Barneville, 1863)	M	m							1
Clypastraea pusilla (Gyllenhal, 1810)	M	m	3			1		2	2
Orthoperus brunnipes (Gyllenhal, 1808)	M	m			6				5
Sericoderus lateralis (Gyllenhal, 1827)	M	m		3		1	2		6
Cryptophagidae									
Atomaria analis Erichson, 1846	M	m	1			2	1		
Atomaria atricapilla Stephens, 1830	M	m	1						

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Table 2. continued.

Family / Species	Biotope groups	Trophic groups	*Bondarzewia mesenterica*	*Fistulina hepatica*	*Fomitopsis rosea*	*Grifola frondosa*	*Hericium alpestre*	*Hericium coralloides*	*Meripilus giganteus*
Cryptophagus dentatus (Herbst, 1793)	M	m	1	36	2	3	4	12	8
Cryptophagus dorsalis C. R. Sahlberg, 1819	M	m	7	5	2	8	5	5	9
Cryptophagus pilosus Gyllenhal, 1827	M	m		3	1	3	2		
Cryptophagus pubescens Sturm, 1845	M	m		1					1
Cryptophagus scutellatus Newman, 1834	M	m		5		2	2		1
Micrambe abietis (Paykull, 1798)	M	m	1	4			1	2	1
Curculionidae									
Acalles camelus (Fabricius, 1792)	S	sx	1	1	1	4	1	1	4
Anisandrus dispar (Fabricius, 1792)	M	m		1			3		
Trypodendron domesticum (Linnaeus, 1758)	M	m	2	2	2	1			1
Trypodendron signatum (Fabricius, 1792)	M	m		1					1
Xyleborinus attenuatus (Blandford, 1894)	M	m					1	1	
Xyleborinus saxesenii (Ratzeburg, 1837)	M	m	2	1	4				
Xyleborus monographus (Fabricius, 1792)	M	m				2	3		
Elateridae									
Ampedus pomorum (Herbst, 1784)	S	z		1		1	2		
Melanotus castanipes (Paykull, 1800)	S	z			2	3		2	1
Melanotus villosus (Geoffroy, 1785)	S	z		1	4			2	1
Endomychidae									
Endomychus coccineus (Linnaeus, 1758)	M	m			1				
Erotylidae									
Dacne bipustulata (Thunberg, 1781)	M	m	7	4	4	2	20	10	15
Triplax aenea (Schaller, 1783)	M	m	1			1			
Eucnemidae									
Eucnemis capucina Ahrens, 1812	S	sx				1			
Hylis foveicollis (C. G. Thomson, 1874)	S	sx	1		2		3		1
Melasis buprestoides (Linnaeus, 1761)	S	sx		9	3	5	4	2	1
Histeridae									
Dendrophilus punctatus (Herbst, 1792)	S	z					2		

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Table 2. continued.

Family / Species	Biotope groups	Trophic groups	*Bondarzewia mesenterica*	*Fistulina hepatica*	*Fomitopsis rosea*	*Grifola frondosa*	*Hericium alpestre*	*Hericium coralloides*	*Meripilus giganteus*
Laemophloeidae									
Cryptolestes corticinus (Erichson, 1846)	C	z	1			1			1
Cryptolestes ferrugineus (Stephens, 1831)	C	z						1	
Leptophloeus alternans (Erichson, 1846)	C	z	1	2	1	1			
Latridiidae									
Cartodere nodifer (Westwood, 1839)	M	m	1	5		2	4		
Corticaria pineti Lohse, 1960	M	m		1	1				
Corticaria serrata (Paykull, 1798)	M	m				1		1	1
Corticarina lambiana (Sharp, 1910)	M	m					1	1	1
Corticarina minuta (Fabricius, 1792)	M	m	3		4	4	2	5	1
Corticarina similata (Gyllenhal, 1827)	M	m		1	2				
Cortinicara gibbosa (Herbst, 1793)	M	m	17	43	21	16	13	22	13
Dienerella ruficollis (Marsham, 1802)	M	m	1	16	8	13	8	4	94
Enicmus fungicola C. G. Thomson, 1868	MY	my	1	6	1		1	1	1
Enicmus histrio Joy & Tomlin, 1910	MY	my						1	1
Enicmus rugosus (Herbst, 1793)	MY	my			4	2	12	3	
Enicmus transversus (A. G. Olivier, 1790)	MY	my	4	1	3	1	3		1
Latridius hirtus Gyllenhal, 1827	MY	my				1	1		1
Latridius porcatus (Herbst, 1793)	MY	my					1	2	3
Stephostethus angusticollis (Gyllenhal, 1827)	M	m	2	4	1	3	1		1
Leiodidae									
Agathidium confusum Brisout de Barneville, 1863	MY	my	2		12	4	1	3	14
Agathidium nigripenne (Fabricius, 1792)	MY	my	2	15	2	4	5	1	3
Agathidium seminulum (Linnaeus, 1758)	MY	my	4	3	3	3	4	3	2
Agathidium varians Beck, 1817	MY	my		1	1				
Anisotoma humeralis (Fabricius, 1792)	MY	my	1	4	1	3	9	2	
Lucanidae									
Platycerus caraboides (Linnaeus, 1758)	S	sx		1	1				
Lycidae									
Dictyoptera aurora (Herbst, 1784)	S	sx							1

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Table 2. continued.

Family / Species	Biotope groups	Trophic groups	*Bondarzewia mesenterica*	*Fistulina hepatica*	*Fomitopsis rosea*	*Grifola frondosa*	*Hericium alpestre*	*Hericium coralloides*	*Meripilus giganteus*
Lymexylidae									
Elateroides dermestoides (Linnaeus, 1761)	M	m	5	4		1	1		1
Melandryidae									
Abdera flexuosa (Paykull, 1799)	M	m					1		
Conopalpus testaceus (A. G. Olivier, 1790)	S	sx							1
Orchesia fasciata (Illiger, 1798)	S	sx	1	5	3	2	1		1
Orchesia micans (Panzer, 1793)	M	m				1			
Orchesia minor Walker, 1837	M	m		1		1		3	
Phryganophilus auritus Motschulsky, 1845	S	sx					1		
Serropalpus barbatus (Schaller, 1783)	S	sx			1				
Monotomidae									
Rhizophagus bipustulatus (Fabricius, 1792)	C	z	17	37	16	11	14	28	18
Rhizophagus cribratus (Gyllenhal, 1827)	C	z			1				
Rhizophagus dispar (Paykull, 1800)	C	z			1				
Rhizophagus fenestralis (Linnaeus, 1758)	C	z	1	1	2			2	5
Mordelidae									
Tomoxia bucephala A. Costa, 1854	S	sx						1	
Mycetophagidae									
Litargus connexus (Geoffroy, 1785)	M	m	1	5	3	2	3	7	3
Mycetophagus ater (Reitter, 1879)	M	m					2		1
Mycetophagus atomarius (Fabricius, 1787)	M	m	1		1			1	
Mycetophagus multipunctatus Fabricius, 1792	M	m	5	1	6	8	6	4	7
Mycetophagus piceus (Fabricius, 1777)	M	m	1					1	1
Mycetophagus quadriguttatus P. W. J. Müller, 1821	M	m							1
Mycetophagus quadripustulatus (Linnaeus, 1760)	M	m					1	2	
Nitidulidae									
Cybocephalus fodori Endrödy-Younga, 1965	M	z							1
Cyllodes ater (Herbst, 1792)	M	m		1		1			1
Epuraea biguttata (Thunberg, 1784)	C	z	2	9					5

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Table 2. continued.

Family / Species	Biotope groups	Trophic groups	*Bondarzewia mesenterica*	*Fistulina hepatica*	*Fomitopsis rosea*	*Grifola frondosa*	*Hericium alpestre*	*Hericium coralloides*	*Meripilus giganteus*
Glischrochilus quadripunctatus (Linnaeus, 1758)	C	z		1			1		
Soronia grisea (Linnaeus, 1758)	C	m		1					
Ptinidae									
Cacotemnus rufipes (Fabricius, 1792)	S	sx							1
Dorcatoma dresdensis Herbst, 1792	M	m	1		2		1		2
Dorcatoma lomnickii Reitter, 1903	M	m	1		3	1			3
Dorcatoma robusta A. Strand, 1938	M	m							1
Hemicoelus canaliculatus (C. G. Thomson, 1863)	S	sx				2			
Ptilinus pectinicornis (Linnaeus, 1758)	S	sx	1			4	2	2	6
Pyrochroidae									
Schizotus pectinicornis (Linnaeus, 1758)	C	sx							1
Salpingidae									
Salpingus planirostris (Fabricius, 1787)	C	z	9	8	8	5	11	16	1
Salpingus ruficollis (Linnaeus, 1760)	C	z	10	14	8	10	7	17	10
Sphaeriestes castaneus (Panzer, 1796)	C	z							1
Scraptiidae									
Anaspis frontalis (Linnaeus, 1758)	S	sx	2	1	2	4	2	3	1
Anaspis rufilabris (Gyllenhal, 1827)	S	sx	4	4	8	1	1	4	5
Anaspis thoracica (Linnaeus, 1758)	S	sx	1			1		1	
Cyrtanaspis phalerata (Germar, 1847)	S	sx	2			3			1
Scydmaenidae									
Neuraphes taplarum Lokay, 1920	MI	z				1	1		1
Stenichnus collaris (P. W. J. Müller & Kunze, 1822)	MI	z	1					1	
Sphindidae									
Sphindus dubius (Gyllenhal, 1808)	MY	my				1	1		
Staphylinidae									
Atheta crassicornis (Fabricius, 1793)	M	z					1	1	
Bibloporus bicolor (Denny, 1825)	C	z		1	1				
Bibloporus minutus Raffray, 1914	C	z	1	1		2	2	5	

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Table 2. continued.

Family / Species	Biotope groups	Trophic groups	*Bondarzewia mesenterica*	*Fistulina hepatica*	*Fomitopsis rosea*	*Grifola frondosa*	*Hericium alpestre*	*Hericium coralloides*	*Meripilus giganteus*
Bolitochara obliqua Erichson, 1837	M	z			2				1
Euplectus infirmus Raffray 1910	C	z	1				1		
Euplectus karstenii (Reichenbach, 1816)	C	z		1			1		
Euplectus punctatus Mulsant & Rey, 1861	C	z					1	2	
Leptusa pulchella (Mannerheim, 1830)	C	z					1		
Leptusa ruficollis (Erichson, 1839)	C	z	1				2		
Lordithon lunulatus (Linnaeus, 1760)	M	z					1	1	
Scaphisoma agaricinum (Linnaeus, 1758)	M	m	2			1	1	4	1
Sepedophilus littoreus (Linnaeus, 1758)	S	z			1				
Sepedophilus testaceus (Fabricius, 1793)	M	m						1	
Tenebrionidae									
Scaphidema metallicum (Fabricius, 1792)	S	sx	1						
Tetratomidae									
Tetratoma ancora Fabricius, 1790	M	m	1	5	4	4			
Tetratoma fungorum Fabricius, 1790	M	m	1						3
Throscidae									
Aulonothroscus brevicollis (Bonvouloir, 1859)	M	m	2	2	23	8	60	9	8
Trixagus carinifrons (Bonvouloir, 1859)	M	m	47	26	15	46	45	72	52
Trixagus dermestoides (Linnaeus, 1767)	M	m	16	6	6	7	10	5	15
Trogossitidae									
Grynocharis oblonga (Linnaeus, 1758)	S	sx						1	
Zopheridae									
Synchita humeralis (Fabricius, 1792)	S	m						1	

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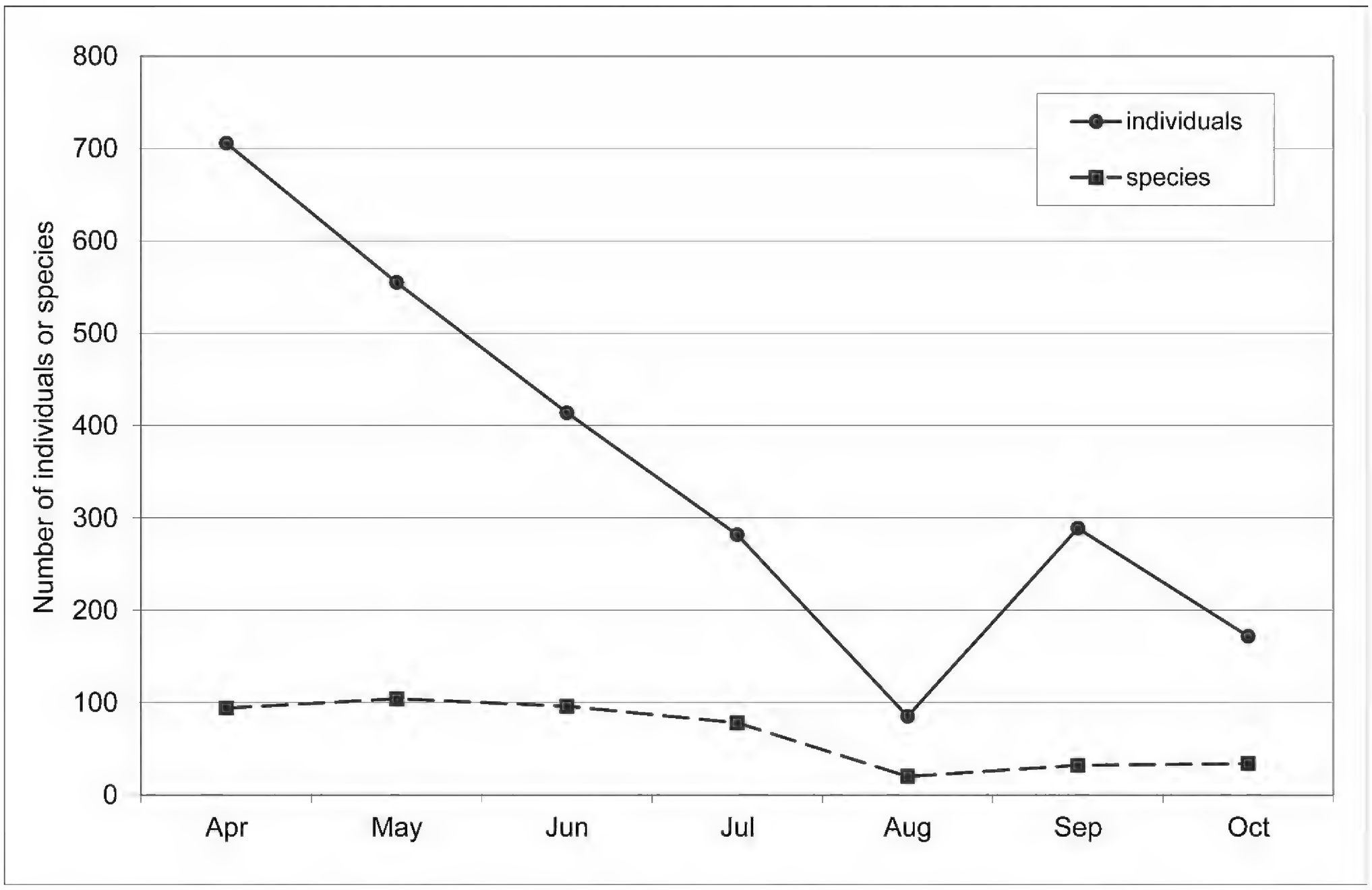


Fig. 3. Seasonal variation in numbers of individuals and species of beetles caught in traps with mycelium of wood-decay fungi on sawdust substrate.

third (20.3%). Species feeding on slime moulds were the least numerous (myxomycophages – 9.0%).

The largest number of individuals and species was caught in spring months (Fig. 3). Among the dominant species, *Rhizophagus bipustulatus* was caught primarily in early spring (April–May), *Cortinicara gibbosa* in spring (April–June) and autumn (October), whereas *Dienerella ruficollis*, in late summer and autumn (August–October). The seasonal dynamics of species of the family Throscidae shows that among *Aulonothroscus brevicollis, Trixagus carinifrons* (dominant species), and *T. dermestoides*, only *T. dermestoides* has one peak of abundance (in June), while the other two species have two peaks of abundance. This suggests that the latter species are bivoltine, i.e., have two generations a year. The first generation peaks in May, whereas the second generation of *A. brevicollis*, in July, and that of *T. carinifrons*, in September (Fig. 4).

Cluster analysis of species composition of the catch for the seven bait variants allowed us to distinguish two clusters of species composition. The first cluster was formed by the two beetle assemblages attracted to sawdust substrate with mycelium of *F. hepatica* and *F. rosea,* i.e., the fungi causing brown rot (Fig. 5). The second cluster was formed by all the other assemblages, including all species being attracted by sawdust substrate with the fungi causing white rot: *B. mesenterica, G. frondosa, H. alpestre, H. coralloides,* and *M. giganteus*. The latter cluster is composed again of two groups of species: the beetles associated with fungi of the genus *Hericium*, and beetles

Table 3. Biotope groups of beetles caught in traps with mycelium of wood-decay fungi on sawdust substrate..

Biotope group	Number of species		Number of individuals	
	S	%	N	%
Corticoles	23	17.3	391	19.2
Mycetocoles	64	48.1	1303	63.9
Myrmetocoles	2	1.5	5	0.2
Myxomycetocoles	12	9.0	170	8.3
Saproxylocoles	32	24.1	169	8.3

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Table 4. Trophic groups of beetles caught in traps with mycelium of wood-decay fungi on sawdust substrate.

Trophic groups	Number of species		Number of individuals	
	S	%	N	%
Mycetophages	62	46.6	1297	63.6
Myxomycophages	12	9.0	170	8.3
Saproxylophages	27	20.3	146	7.2
Zoophages	32	24.1	425	20.9

associated with the other fungi causing white rot (Fig. 5). A similar result was obtained using the Nonmetric Multidimensional Scaling analysis (Fig. 6).

In the cluster composed of beetles attracted by sawdust substrate with brown rot fungi, the dominant species were *Cortinicara gibbosa* (11.2%), *Rhizophagus bipustulatus* (9.3%), *Trixagus carinifrons* (7.2%), and *Cryptophagus dentatus* (6.7%) (Fig. 7). The most frequently caught species specific to brown rot (absent from the second cluster) was *Corticarina similata* (three individuals in three traps).

In the cluster composed of beetles attracted by sawdust substrate with white rot fungi, the dominant species were *Trixagus carinifrons* (17.8%), *Dienerella ruficollis* (8.2%), *Rhizophagus bipustulatus* (6.0%), *Aulonothroscus brevicollis* (5.9%), and *Cortinicara gibbosa* (5.5%) (Fig. 8). The most frequent species in the white rot were *Ptilinus pectinicornis* (15 individuals in 12 traps), *Scaphisoma agaricinum* (nine individuals in nine traps), and *Clypastraea pusilla* (eight individuals in six traps).

DISCUSSION

Trapping of 133 species of tree-fungus beetles with the use of sawdust substrate with mycelium during one growing season is a methodological success. As many as 90 of the species were recorded in the Experimental Forest Station in Rogów for the first time, and two new species for the fauna of Poland were found: *Corticaria pineti*

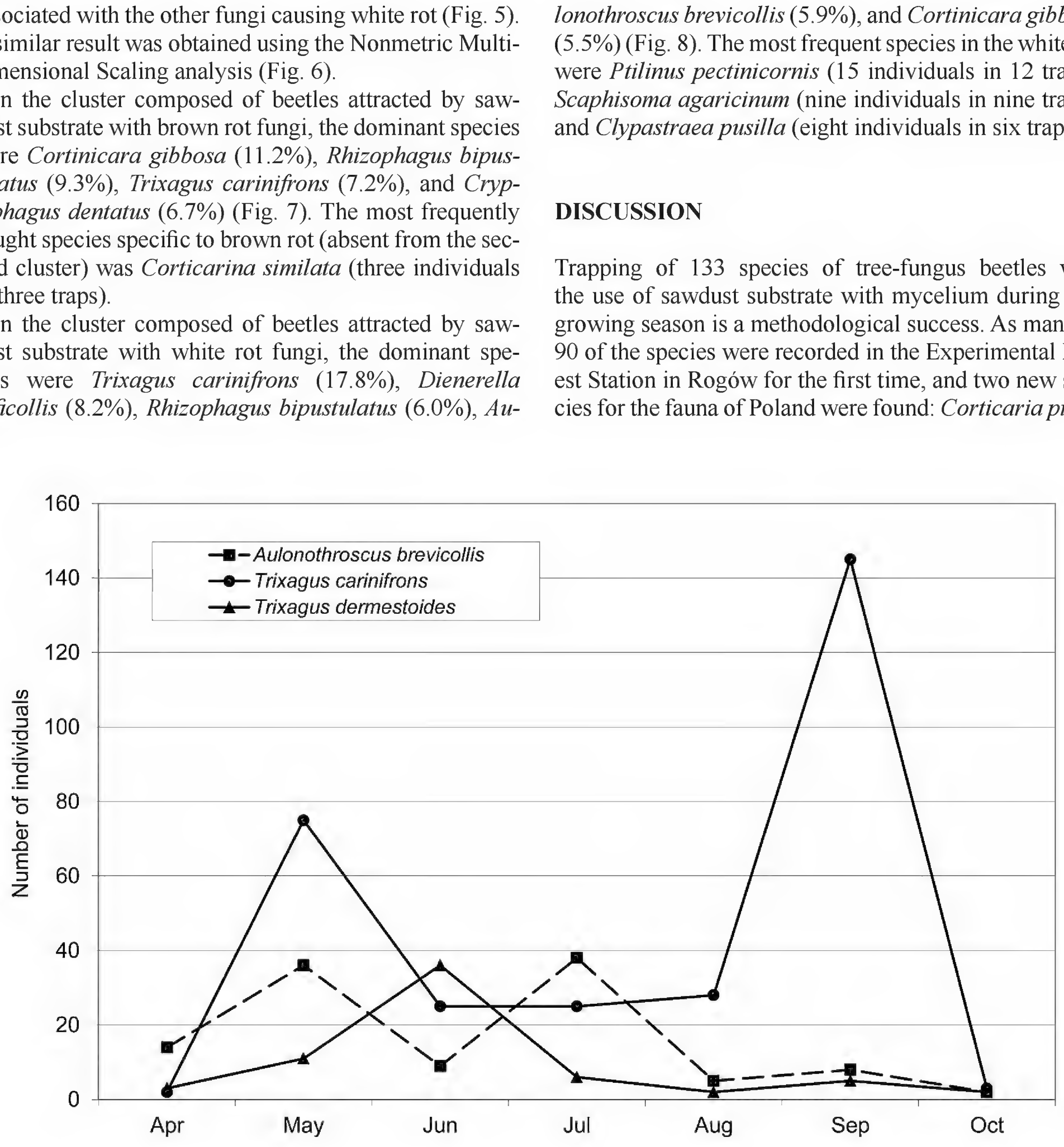


Fig. 4. Seasonal variation in abundance of species of the family Throscidae caught in traps with mycelium of wood-decay fungi on sawdust substrate.

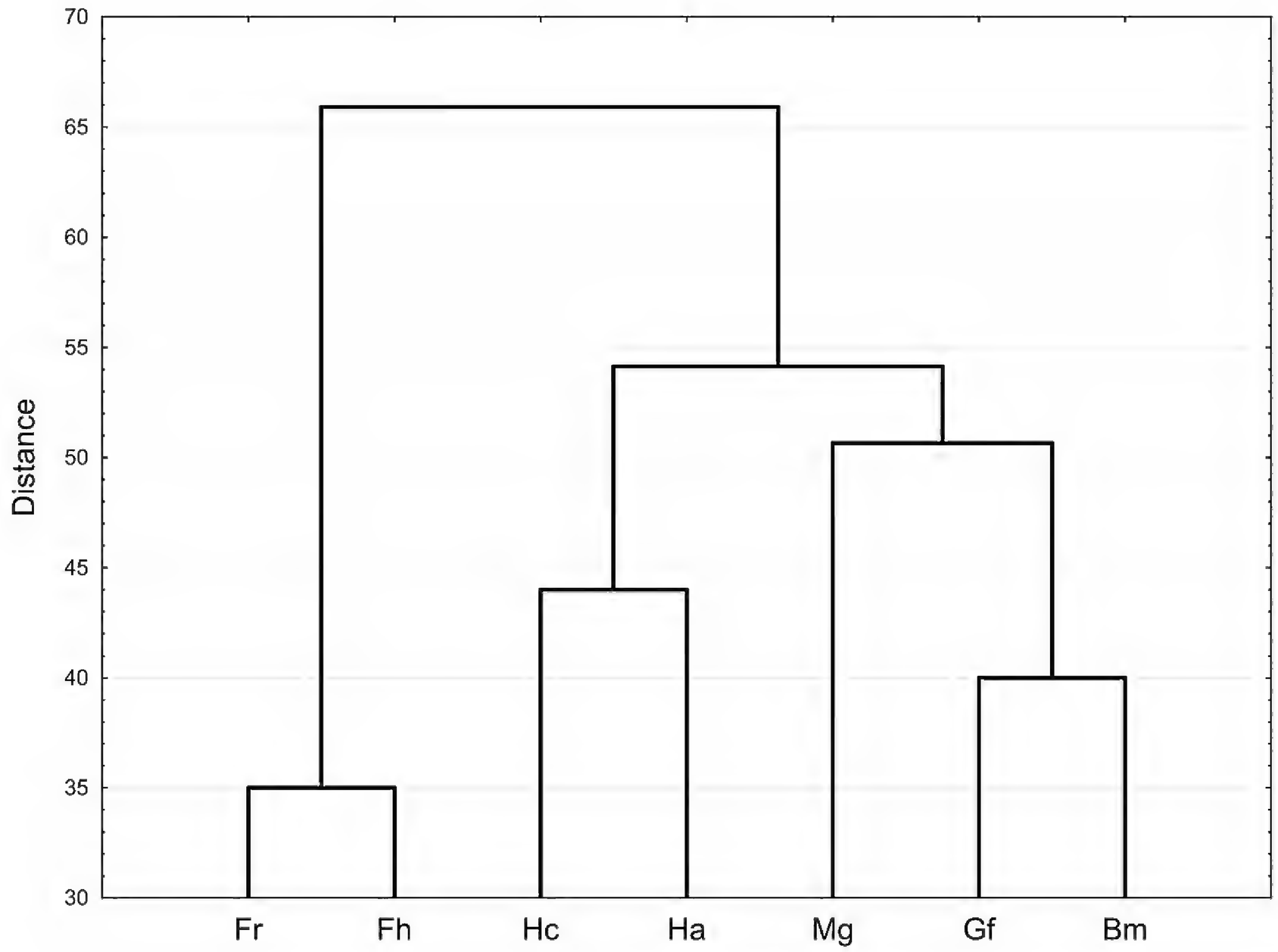


Fig. 5. Faunistic similarity of communities of beetles of wood-decay fungi (Cluster analysis), caught in traps with mycelium on sawdust substrate. Abbreviations: Bm = *Bondarzewia mesenterica*; Fr = *Fomitopsis rosea*; Fh = *Fistulina hepatica*; Gf = *Grifola frondosa*; Ha = *Hericium alpestre*; Hc = *Hericium coralloides*; Mg = *Meripilus giganteus*.

and *Euplectus infirmus*. The former is a rarely reported species living on moulds, known mostly from Central Europe and Scandinavia, reaching south to Greece and Italy. The latter species lives under the bark and has an Atlantic distribution, extending to Italy, Croatia, and Greece in the south and Germany in the east. It is known also from Morocco and Canary Islands. Its record in central Poland moves its eastern distribution limit more than 300 km eastward from records reported in the literature (Borowski et al. 2010).

Beetle species recorded in this study have various microbiotope preferences (mycetocoles, saproxylocoles, corticoles, myxomycetocoles, myrmetocoles). Some of them develop exclusively on fruiting bodies of tree fungi (e.g., *Orchesia micans*, *Cis micans*) or are spore-eating species (e.g., *Scaphisoma* spp.). Some others develop on fruiting bodies of tree fungi as well as mushrooms, e.g., *Dacne bipustulata* in fruiting bodies of tree fungi (Burakowski et al. 1986) and in mushrooms of the genus *Cortinarius* (Pers.) Gray (Borowski 2006). Zoophages were also numerous in the samples (e.g., species of the genus *Rhizophagus* Herbst). Johansson et al. (2006) confirmed that fruiting bodies of tree fungi attract not only beetles that feed on fungi but also many predatory species.

In total, the family Throscidae was represented most numerously, by 480 individuals of three species: *Aulonothroscus brevicollis*, *Trixagus dermestoides*, and *T. carinifrons*. Burakowski (1991) reported that species of this family are rarely found in the field, so their ecology is poorly studied. Supposedly they live in the soil or litter, near roots colonized by mycorrhizal fungi. Thanks to the applied trapping method, we collected new information on the ecology and phenology of emergence of the three species mentioned above. The presented results indicate that *T. carinifrons* and *A. brevicollis* have two peaks of abundance during the year, whereas *T. dermestoides* has only one. The existence of two peaks of abundance in *A. brevicollis* and one peak in *T. dermestoides* was reported also earlier by Leseigneur (2004). According to Hardersen et al. (2014), Throscidae were always present with two or three species, from early April to early November, mainly in Malaise traps at ground layer. Van Meer (1998) supposes that larvae of *A. brevicollis* can develop on dry rotten wood, very much like larvae of the closely related *A. laticollis* Rybinsky, 1897, which were observed by him in dry rotten oak wood. Mertlik & Leseigneur (2007) indicate that imagines of these species overwinter in dead wood. The luring properties of the substrate with mycelium and the presence of eggs and larvae of insects could be the causes of the high abundance of *Rhizophagus bipustulatus, Salpingus ruficollis*, and *S. planirostris*. According to Nunberg (1967), *R. bi-*

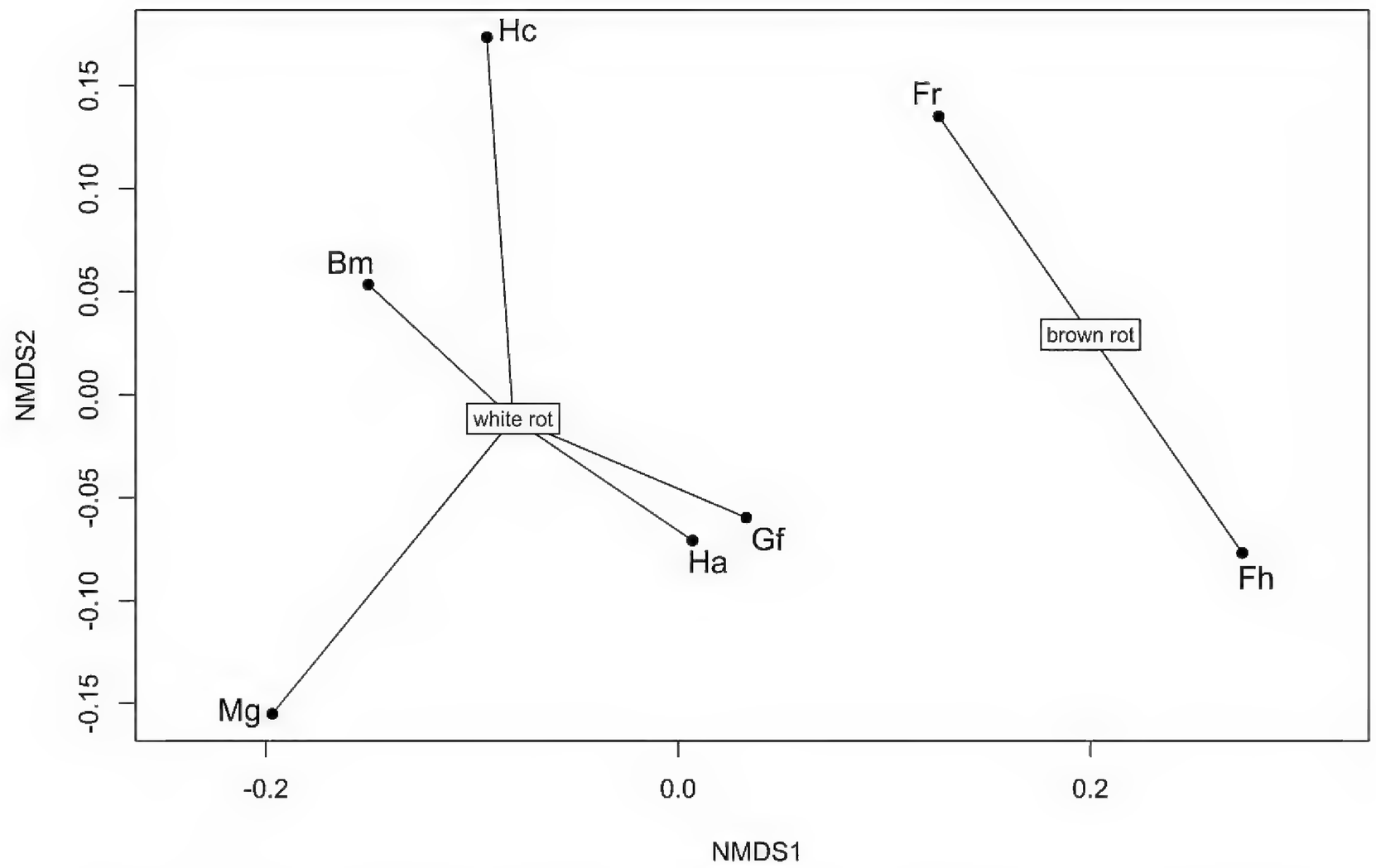


Fig. 6. Faunistic similarity of communities of beetles of wood-decay fungi (Nonmetric Multidimensional Scaling analysis), caught in traps with mycelium on sawdust substrate Abbreviations: Bm = *Bondarzewia mesenterica*; Fr = *Fomitopsis rosea*; Fh = *Fistulina hepatica*; Gf = *Grifola frondosa*; Ha = *Hericium alpestre*; Hc = *Hericium coralloides*; Mg = *Meripilus giganteus*.

pustulatus is predatory, living under the bark, or rarely in rotten wood, feeding mostly on eggs, larvae, free pupae and excrements of various insects and fungi growing at their feeding sites. Mendel et al. (1990) list it among

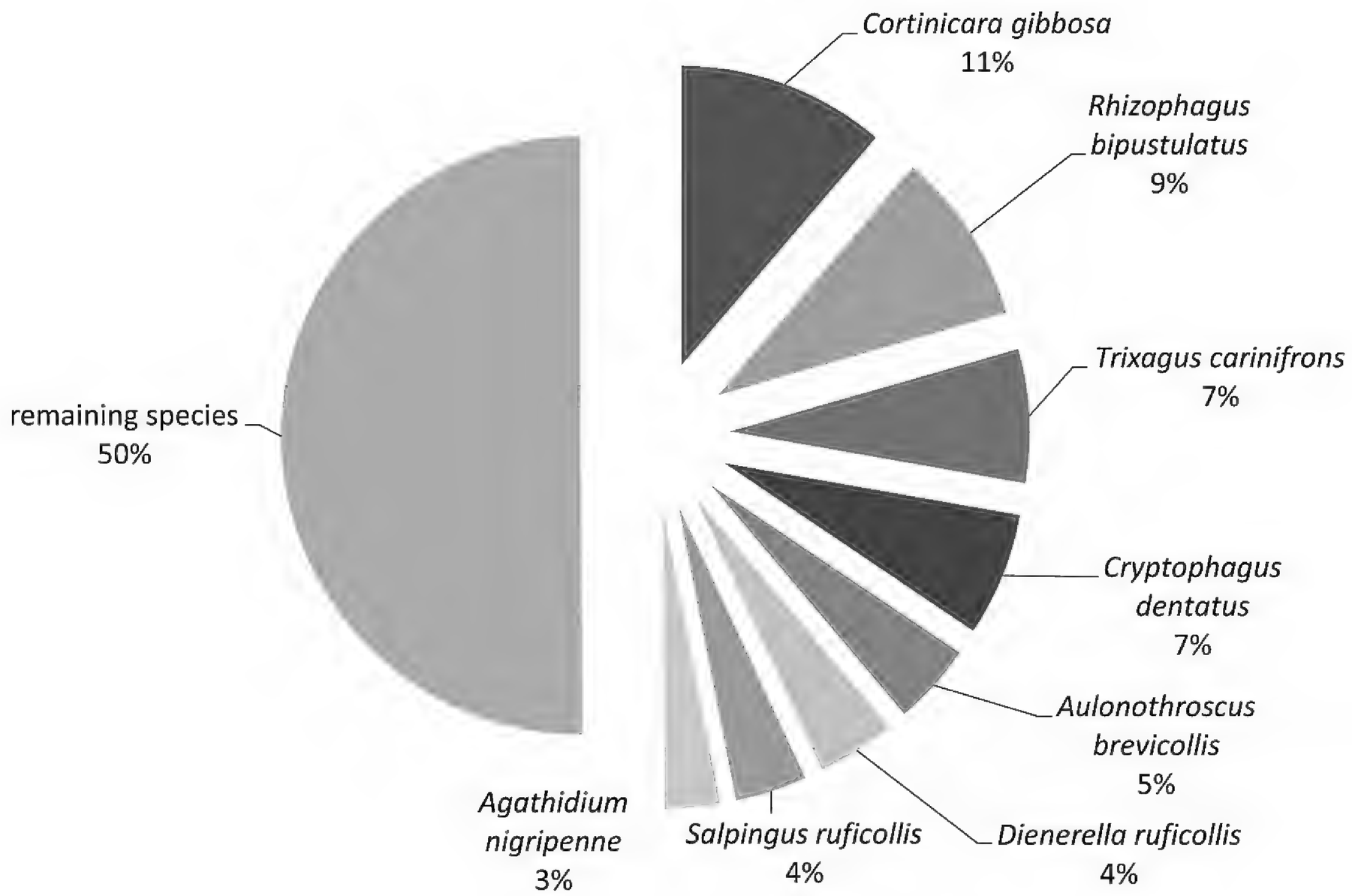


Fig. 7. Contributions of species to the total number of beetles attracted by sawdust substrate with fungi causing brown rot.

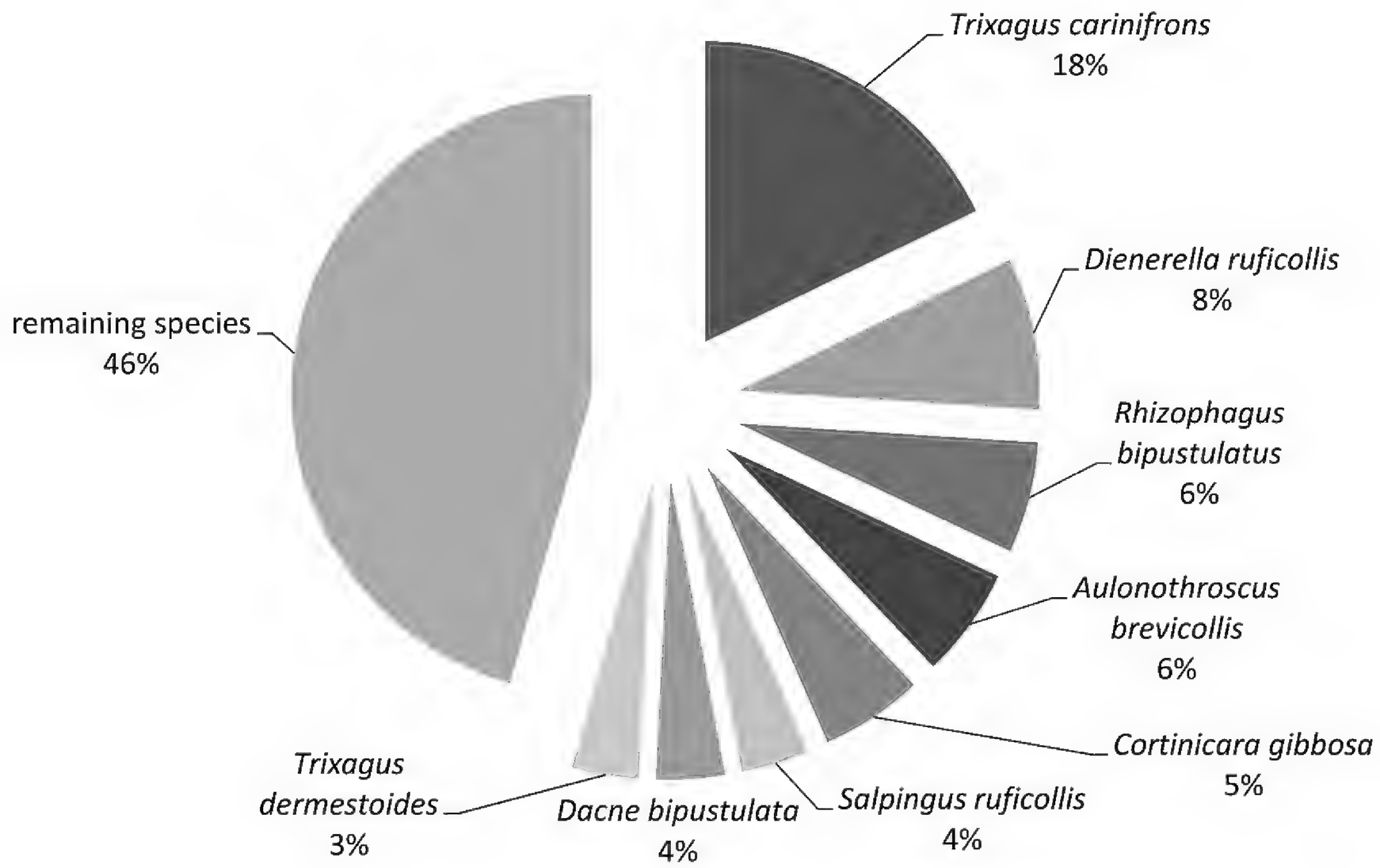


Fig. 8. Contributions of species to the total number of beetles attracted by sawdust substrate with fungi causing white rot.

predators feeding on bark beetles of the genera *Tomicus* Latreille, *Orthotomicus* Ferrari, and *Pityogenes* Bedel. It is also known that larvae and imagines of *S. planirostris* prey on bark beetles (Young 1991). The most abundant species among the trapped beetles included also *Cortinicara gibbosa*, *Dienerella ruficollis*, and *Cryptophagus dentatus*. They are some of the most common mould-eating insects.

The applied sawdust substrate with mycelium of wood-decay fungi attracted much more mycetobiontic beetles than reported in earlier studies of fruiting bodies of these fungal species (Scheerpeltz & Höfler 1948; Benick 1952; Burakowski et al. 1986, 1987; Nikitsky 1993; Krasutsky 1995, 1997; Nikitsky & Schigel 2004, 2007; Borowski 2006). In traps with mycelium of *G. frondosa*, we found 31 species of mycetobiontic beetles that were not reported earlier from this fungus, with *F. hepatica* 25 species, with *F. rosea* 24 species, with *H. coralloides* 21 species, and with *M. giganteus* 32 species. For the other two species of fungi, there are no published data on mycetobiontic beetles recorded on their fruiting bodies, but we found 29 species in traps with mycelium of *H. alpestre* and 27 species in those with *B. mesenterica.* According to Borowski (2006, 2007), 259 mycetobiontic beetles are reported from Poland, whereas 60 species were caught in our study. The findings of Piętka & Borowski (2011a) in the forest reserve "Las Natoliński" in Warsaw indicate that the traps with mycelium are highly effective in catching mycetobiontic beetles. Numerous fruiting bodies of *F. hepatica* in that area resulted in a relatively high abundance of the beetle *Triphyllus bicolor*, which was caught in traps with its mycelium. As many as 32 individuals of this rare mycetophagous species were trapped there. Interestingly, in that reserve, between the traps with mycelium of *F. hepatica*, traps with mycelium of another fungal species were located (*G. frondosa*, found on oaks), but no individual *T. bicolor* was caught in them.

In the collected material, two autonomous faunistic clusters of beetles of wood-decay fungi are noticeable: one associated with brown rot fungi, and the other with white rot fungi. The beetle communities attracted by sawdust substrate with brown rot fungi were dominated by *Cortinicara gibbosa*, *Rhizophagus bipustulatus, Cryptophagus dentatus*, and *Trixagus carinifrons*. The beetle communities attracted by sawdust substrate with white rot fungi were dominated by the same species except *C. dentatus*, but with the addition of *Dienerella ruficollis* and *Aulonothroscus brevicollis.* The three shared species are beetles living on moulds or their predators. Three beetle species were specific to the cluster composed of beetles attracted by traps with white rot fungi: saproxylophagous *Ptilinus pectinicornis* and mycetophagous *Scaphisoma agaricinum*, and *Clypastraea pusilla*. These beetles were caught exclusively in traps with mycelium of white rot fungi. Piętka & Borowski (2011b) reported that *P. pectinicornis* was very numerous (32.8% of the total catch) in beech stands in Świętokrzyski National Park.

It was caught there in traps with sawdust substrate and mycelium of a white rot fungus, *Trametes gibbosa* (Pers.) Fr. Leather et al. (2014) confirm that *Ptilinus pectinicornis* commonly associated with dry and exposed beech wood was significantly associated with infested logs by *Hypholoma fasciculare* (Huds.) P. Kumm., which also causes white rot of wood.

The sawdust substrates with mycelium of wood-decay fungi, prepared in laboratory conditions, constituted a free and attractive ecological niche for many species.

CONCLUSIONS

The sawdust substrates with mycelium of wood-decay fungi, used in traps, attract mycetophilic and mycetobiontic beetles. In the study period (April-October 2008) we caught 73 mycetophilic species and 60 mycetobiontic species of beetles. This bait type was effective in the trapping of beetles associated with wood-decay fungi. Two new species for the fauna of Poland were recorded in this study: the mycetophilic *Euplectus infirmus* and the mycetobiontic *Corticarina pineti*. In the tree-fungus beetle community, mycetophages and zoophages feeding on them were the major trophic groups, while mycetocoles were the major microhabitat group. In the collected material, two clusters of beetle species of wood-decay fungi can be distinguished. The first one is associated with brown rot fungi (*Fistulina hepatica, Fomitopsis rosea*), and the other with white rot fungi (*Bondarzewia mesenterica, Grifola frondosa, Hericium alpestre, H. coralloides, Meripilus giganteus*). It seems that this method can be applied in studies on diversity of tree-fungus beetles, valorisation of forests and monitoring of environmental processes.

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The genus *Trynocoris* Herring, 1976 (Heteroptera: Miridae: Cylapinae) is no longer monotypic: *T. costaricaensis* sp. nov. from Guanacaste, north-western Costa Rica

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Abstract. A revised diagnosis of the genus *Trynocoris* Herring, 1976 is presented and a new species, *Trynocoris costaricaensis* sp. nov., is described based on specimens collected in Costa Rica. Colour photographs of the adult and illustrations of the male genitalia are provided for the new species. Scanning electron micrographs of selected structures of the new species are also given.

Key words. Biodiversity, Fulviini, new species, Neotropics, plant bugs, taxonomy, true bugs.

INTRODUCTION

The genus *Trynocoris* Herring, 1976 was described as monotypic for *T. lawrencei* Herring, 1976 based on specimens collected in Panama (Herring 1976). The genus was placed in the tribe Fulviini within Cylapinae (Herring 1976). In addition to Fulviini, the subfamily Cylapinae also includes representatives of the tribes Cylapini and Vanniini in the Neotropical Region. Distribution and biology of the New World Cylapinae still remain poorly known, although several genera have been revised and new taxa have been described recently (e.g., Chérot & Carpintero 2016; Wolski 2017; Wolski et al. 2020). Some representatives of Cylapinae (particularly in the tribe Cylapini) are mycetophagous (Wheeler 2001), but *Trynocoris lawrencei* probably feeds on larvae of beetles that live in fungi (Herring 1976). Gorczyca et al. (2019) redescribed *Trynocoris* and *T. lawrencei*, and cited new sampling localities in Panama, Mexico, Ecuador and Nicaragua.

While studying the material collected in Costa Rica in the collection of the Division of Entomology, University of Kansas Natural History Museum (Lawrence, Kansas, USA; KUNHM), the authors found two specimens of a new species of the genus *Trynocoris*. In the present paper we provide a revised diagnosis of the genus and describe the new species. Furthermore, we compare the morphology, including genitalia, of both species of *Trynocoris*.

MATERIAL AND METHODS

The specimens were imaged using the following equipment: Leica M205C stereo microscope with high diffuse dome illumination Leica LED5000 HDI, Leica DFC495 digital camera and Leica application suite 4.12.0 software; Leica DM 3000 upright light microscope with Leica MC 190 HD digital camera and Leica Application Suite ver. 4.13.0 software. SEM photographs were obtained using Phenom XL field emission scanning electron microscope at 10 and 15 kV accelerating voltage with a BackScatter Detector (BSD). Graphic editor Adobe ®Photoshop ver. CS6 was used to edit the figures. Measurements were made with Leica application suite ver. 4.12.0 software and are presented in millimeters (mm). The measured body parts were defined in Wolski (2014). Dissections of male genitalia were done according to Kerzhner and Konstantinov (1999). The original description was used to identify the genus (Herring 1976). Adult terminology used in the text follows Schuh & Weirauch (2020).

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The terminology of the male genital structures follows Kerzhner & Konstantinov (1999), Konstantinov (2003), Cassis (2008) and Schuh & Weirauch (2020).

RESULTS

Taxonomy

Trynocoris Herring, 1976

Trynocoris Herring 1976: 91 (as new genus) [type species: *Trynocoris lawrencei* – original designation].

Trynocoris: Schuh, 1995: 38 (catalog), Schuh, R. T. (2002–2013 On-line Systematic Catalog), Gorczyca 2000: 49 (list of the genera of the tribe Fulviini), Gorczyca 2006: 69 (catalog), Gorczyca et al. 2019: 52 (redescription).

Diagnosis

Distinguished from the other genera of Cylapinae by the following set of characters: body small (< 3.1 mm), oval to elongate oval, dorsum densely and deeply punctured (Figs 1A, 3A), covered with dense, scale-like setae, varying from linear to incrassate; second antennal segment thickened, sometimes flattened laterally; the fourth antennal segment subdivided (Fig. 1A–B; Gorczyca et al. 2019: fig. 1); cuneus short, apex of hemelytra at the level of cuneal fracture bent downward; tarsi two-segmented (Gorczyca et al. 2019: figs 10–12); male genitalia: pygophore trapezoidal, its dorsal wall long, almost as long as ventral wall, aperture of pygophore directed posteriorly; aedeagus thin; ductus seminis long and thin; endosoma membranous; left paramere with apical process broad in dorsal view and with relatively long, thin process on extreme apex; right paramere C-shaped its apical process broad when viewed dorsally with more or less developed process in the middle of right lateral margin (Fig. 2; Gorczyca et al. 2019: figs 17–20).

Remarks

This genus belongs to the tribe Fulviini and the morphological characters that warrant this placement as well as the features indicating close similarity to some fulviines were discussed by Gorczyca et al. (2019).

Herein we confirm the two-segmented tarsi with tarsomere II undivided as one of the diagnostic features of *Trynocoris*. In Cylapinae, the number of the tarsal segments is variable depending on the tribe. The representatives of Bothriomirini, Cylapini, and Rhinomirini possess three-segmented tarsi (Wolski 2017; Namyatova et al. 2019; Namyatova & Cassis 2016, 2019, 2021). In contrast, in the tribe Fulviini, as circumscribed by Gorczyca (2000), the number of tarsal segments is variable depending on the genus. Genera *Carvalhofulvius* Stonedahl & Kovac, 1995 (Stonedahl & Kovac 1995: fig. 8), *Cylapocoris* Carvalho, 1954 (Wolski 2013), *Howefulvius* Schmitz & Štys, 1973 (Schmitz & Štys 1973: fig. 7), *Peritropisca* Carvalho & Lorenzato, 1978 (Wolski & Gorczyca 2014; Namyatova & Cassis 2019), *Sulawesifulvius* Gorczyca, Chérot & Štys, 2004 (Gorczyca et al. 2004: fig. 4; Wolski et al. 2017: fig. 10) and others have two-segmented tarsi, as well as many species of the genera *Fulvius* Stål, 1862 (Gorczyca 2000: figs 23E, 27D; Yasunaga 2000: figs 10–11; Wolski et al. 2018: fig. 45) and *Peritropis* Uhler, 1891 (Wolski & Henry 2012: fig. 81). Three-segmented tarsi are found in *Bironiella* Poppius, 1909 (Namyatova et al. 2016: fig. 19j), *Punctifulvius* Schmitz, 1978 (Yasunaga 2000: fig. 13; Namyatova & Cassis 2019: fig. 10n), *Yamatofulvius* Yasunaga, 2000 (Yasunaga 2000: figs 14–16) and in some species of *Peritropis* (Namyatova et al. 2016: 19I). Recently, Namyatova & Cassis (2019) pointed out that most fulviines, which they included in their phylogenetic analysis, have three-segmented tarsi and suggested that the two-segmented tarsi with the second tarsomere divided observed by many previous authors are in fact three-segmented tarsi. The question whether the tarsi observed among others by Gorczyca & Eyles (1997: fig. 5), Yasunaga (2000: fig. 12), Gorczyca (2002: 12) or Wolski et al. (2018: fig. 53) have two or three segments remains open. However, given the fact that many fulviines possess two-segmented tarsi, with no subdivision of the second segment, unlikely that all these observations are incorrect. Taking into account the existing differences in number of the tarsal segments among the fulviine genera, we believe that the two-segmented tarsi are a helpful character in defining the genus *Trynocoris* in combination with other diagnostic features of this genus herein presented.

Key to the species of the genus *Trynocoris* Herring, 1976

1. Body covered with broadened, scale-like setae (Fig. 3A–B); second antennal segment weakly flattened laterally, covered with thick, scale-like setae ..... ***T. lawrencei*** Herring, 1976
– Body covered with linear setae (Fig. 1); second antennal segment not flattened, somewhat thickened toward the apex, covered with simple setae (Figs 1A, C; 3C) ..... ***T. costaricaensis*** sp. nov.

Trynocoris costaricaensis sp. nov.

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Figs 1–2, 3C, 4C–D

Diagnosis

The new species is similar to *T. lawrencei* (Figs 3A–B, 4A–B) but can be easily separated by the following character states: (1) Second antennal segment (Fig. 1) of female not foliaceous and laterally flattened, but basally and medially cylindrical, apically slightly club-like, its



Fig. 1. *Trynocoris costaricaensis* sp. nov., ♀, holotype (SM0210321 KUNHM-ENT). **A**. Dorsal view. **B**. Ventral view. **C**. Lateral view.

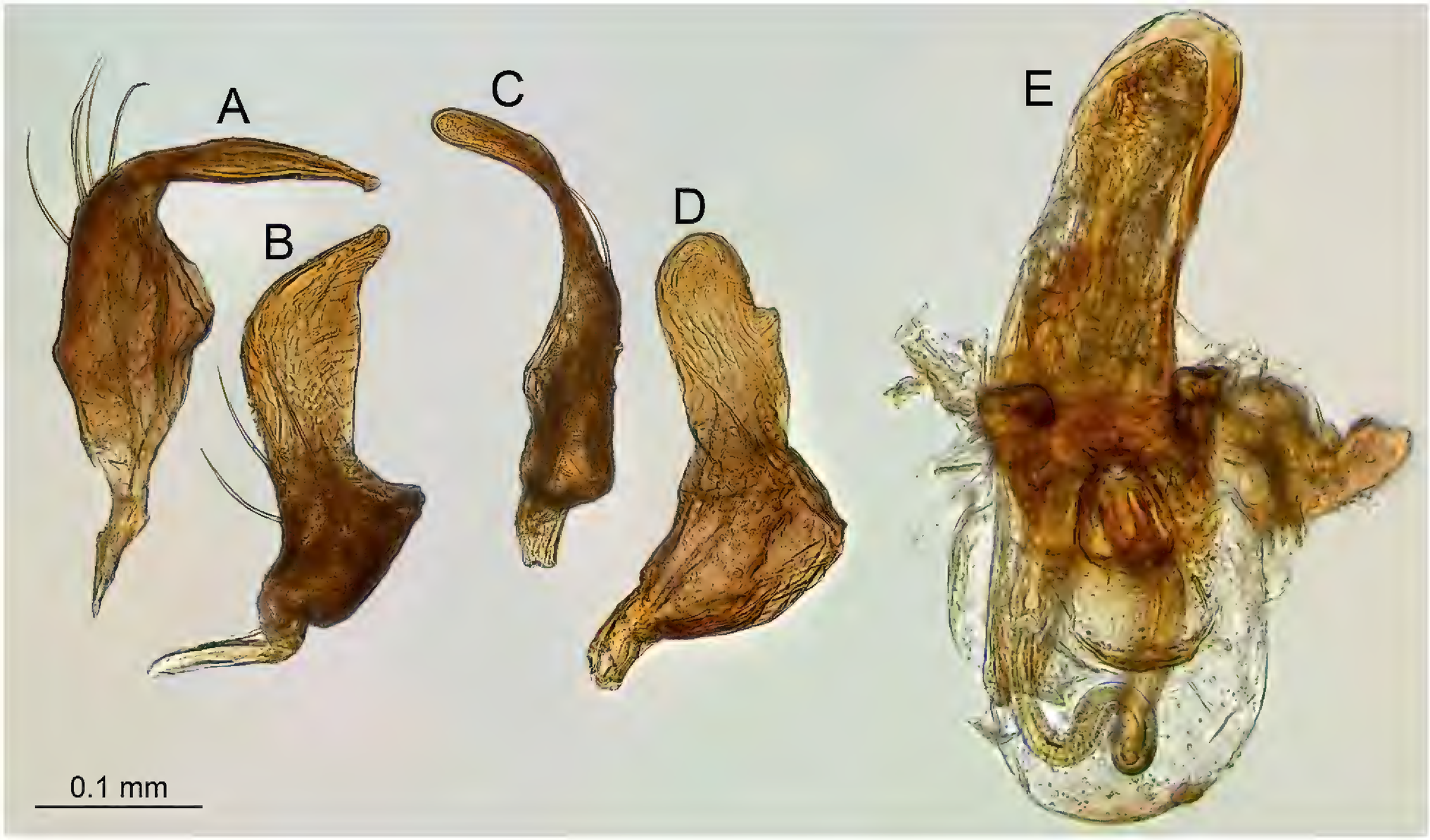


Fig. 2. *Trynocoris costaricaensis* sp. nov., ♂, paratype (SM0210194 KUNHM-ENT), genitalia. **A–B**. Left paramere. **C–D**. Right paramere. **E**. Dorsal view of endosoma.

colour pattern more complex (basally brown, medially orange-brown to orange, apically yellow *versus* evenly red-brown except its dorsal and ventral black margins in *T. lawrencei*). (2) Pilosity of second antennal segment (Fig. 1) limited to long, suberect to erect setae, similar to setae of third and fourth antennal segments (*versus* pilosity of second antennal segment including scale-like setae and thick, simple setae in *T. lawrencei*). (3) Absence of orange-red 'ventral neck or ring' easily visible under the eyes in *T. lawrencei*. (4) Labium reaching ovipositor (Fig. 1B–C) (*versus* in *T. lawrencei* reaching base of the abdomen in the female, but the pygophore in the male). (5) Body covered with setae curved, recumbent, barely widened apically, silvery bright under incident light (Figs 1A, 3C) (*versus* scale-like, whitish, dull, obviously widened apically in *T. lawrencei* (Fig. 3A–B)). (6) In males, the left paramere apical process in dorsal view with apex curved toward the right side; right paramere apical process in dorsal view with a moderately developed medial spine on right lateral margin (Fig. 2B, D).

Etymology

The specific epithet refers to the country where the type locality is found, Costa Rica.

Type material

Deposited at the University of Kansas Natural History Museum (KUNHM) (Lawrence, Kansas, USA).

Holotype

COSTA RICA • ♀; 'COSTA RICA Guanacaste / Cacao Biological Station, 1050 m / 10°55′38″ N, 85°27′7″ W / 11 JUL 2000, leg. J.Ashe, R. Brooks, / Z.Falin CR1ABF00 100 / ex. fogging fungus covering log // SM0210321 / KUNHM-ENT'.

Paratype

COSTA RICA • ♂, damaged and incomplete; 'COSTA RICA: Guanacaste / Cacao Biological Station, 1050 m / 10°55′38″ N, 85°27′7″ W / 11 JUL 2000, leg. J.Ashe, R.Brooks, / Z.Falin CR1ABF00 100 / ex. fogging fungus covering log // SM0210194 / KUNHM-ENT'.

Description

Female

Measurements (in mm). Body (in dorsal view): Length: 3.1, width 1.58. Head: Interocular distance (vertex width): 0.43, width of eye: 0.2, length of antennal segment I: 0.28, II: 0.63, III: 0.28, IV: 0.25. Pronotum: Medial length: 0.6, posterior width of disk: 1.33, length of lateral margin (between anterior and humeral angle): 0.6. Scutellum: Length (mesoscutum excluded): 0.53, length (mesoscutum included): 0.68, width: 0.73. Cuneus: Length: 0.3, width at base: 0.2.

Colouration (Fig. 1A–C). Body black. ***Head***. Vertex (including narrow carina), frons and mandibular plates black. Clypeus and maxillary plates reddish brown. Eyes

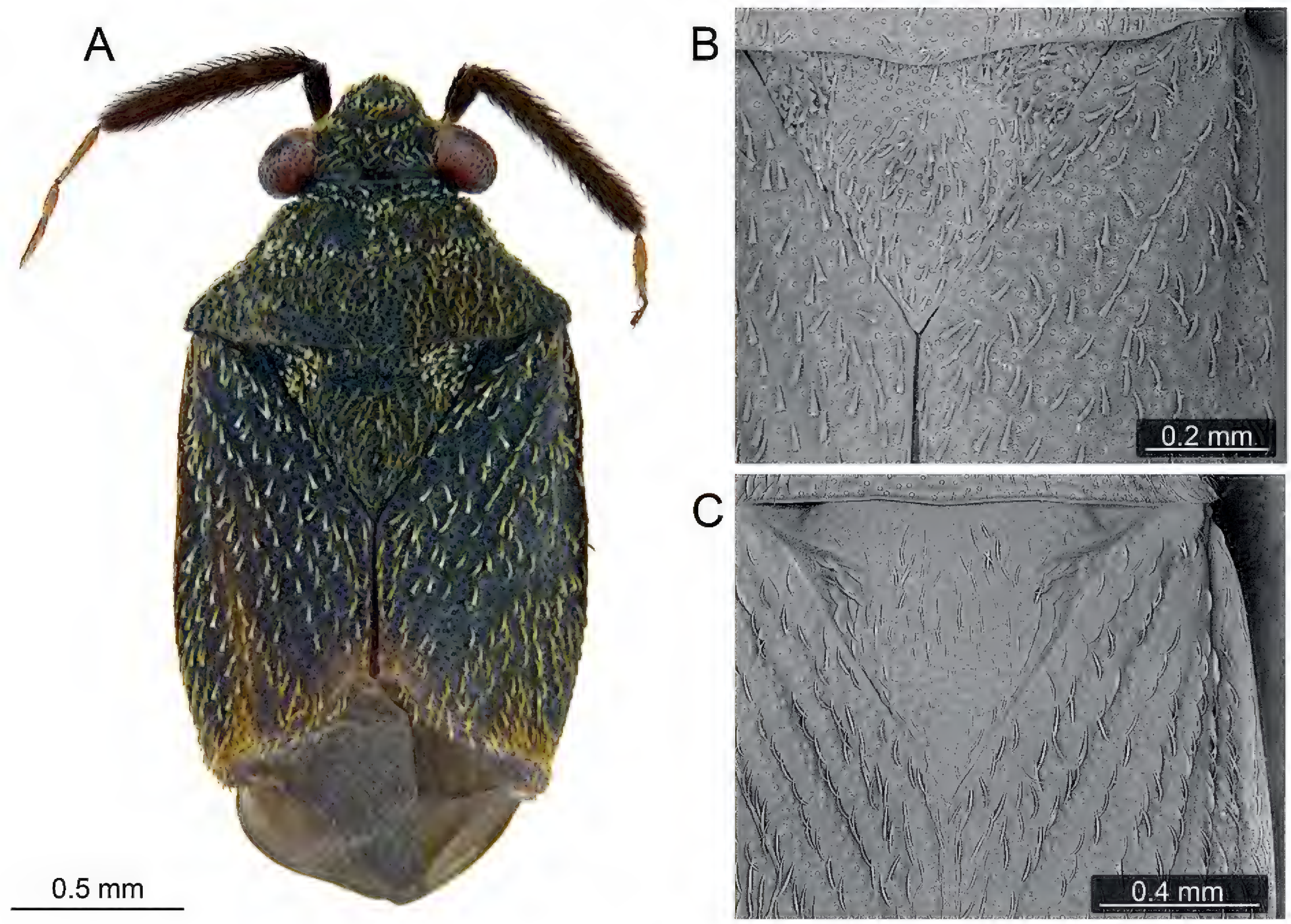


Fig. 3. A. *Trynocoris lawrencei* Herring, 1976, dorsal view. **B**. *T. lawrencei* Herring, 1976, dorsal surface of the body (according Gorczyca et al. 2019). **C**. *T. costaricaensis* sp. nov., ♂, paratype (SM0210194 KUNHM-ENT), dorsal surface of the body.

grey. First antennal segment reddish with a yellowish ring at basal third. Second antennal segment basally brown, medially orange-brown to orange, apically yellow. Third and base of fourth antennal segment brown, the apex of fourth antennal segment black. Labium brown, the first segment apically yellow. ***Thorax***. Pronotum and scutellum evenly black, pronotal collar reddish-brown. Metafemur wide, reddish-brown with dark reddish spots. Metatibia black with yellowish rings. Mesoscutum black, the lateral part brown. Clavus black, the apex yellow to orange. Endocorium black, its apex with a brownish median area and one yellowish spot at the inner corner. Exocorium brown with an elongate submedian longitudinal black stripe and an apical yellow spot. Embolium brown. Membrane grey. Cuneus orange-brown. Pro-, meso- and metapleuron black to reddish black, shining. ***Abdomen.*** Black.

Structure, texture and vestiture (Fig. 1A–C). Body oval to elongate-oval. ***Head***. Declivous. Frons and vertex narrowly and shallowly punctate. Vertex posterior area slightly raised, narrowly carinate. Eyes relatively small, contiguous to the pronotal collar (partially hidden by the eyes laterally). The first antennal segment with relatively short, suberect setae, particularly apically. Second antennal segment bearing long, suberect to erect setae, longer apically, similar to setae of third and fourth antennal segments. The fourth antennal segment subdivided. ***Thorax***. Pronotal collar very short. Pronotal lateral and posterior margins carinate. Pronotal disk punctate, the punctation wider and deeper than dorsal punctation of the head. Pronotal callosities barely visible. Mesoscutum wide, posteriorly convex and laterally marginate. Punctation of mesoscutum and scutellum similar to pronotal punctation (Fig. 3C). Claval vein raised. Clavus and corium with two different type of setae: one short, black, recumbent the other slightly longer and curved, recumbent, barely widened apically, silvery bright under incident light, in rows on the basal part of the corium. Cuneus elongate oval, oblique, with sparse, very short, stiff, black setae. ***Abdomen.*** Thickened, not reaching the apex of membrane. ***Female genitalia.*** (Fig. 4C–D). Bursa copulatrix (= vagina, = genital chamber) totally membranous, devoid of sclerite. Sclerotized rings not visible in available specimens. Posterior wall not easily recognizable.

Male

Similar to female but smaller in size. The only male specimen is seriously damaged, headless and without trochan-

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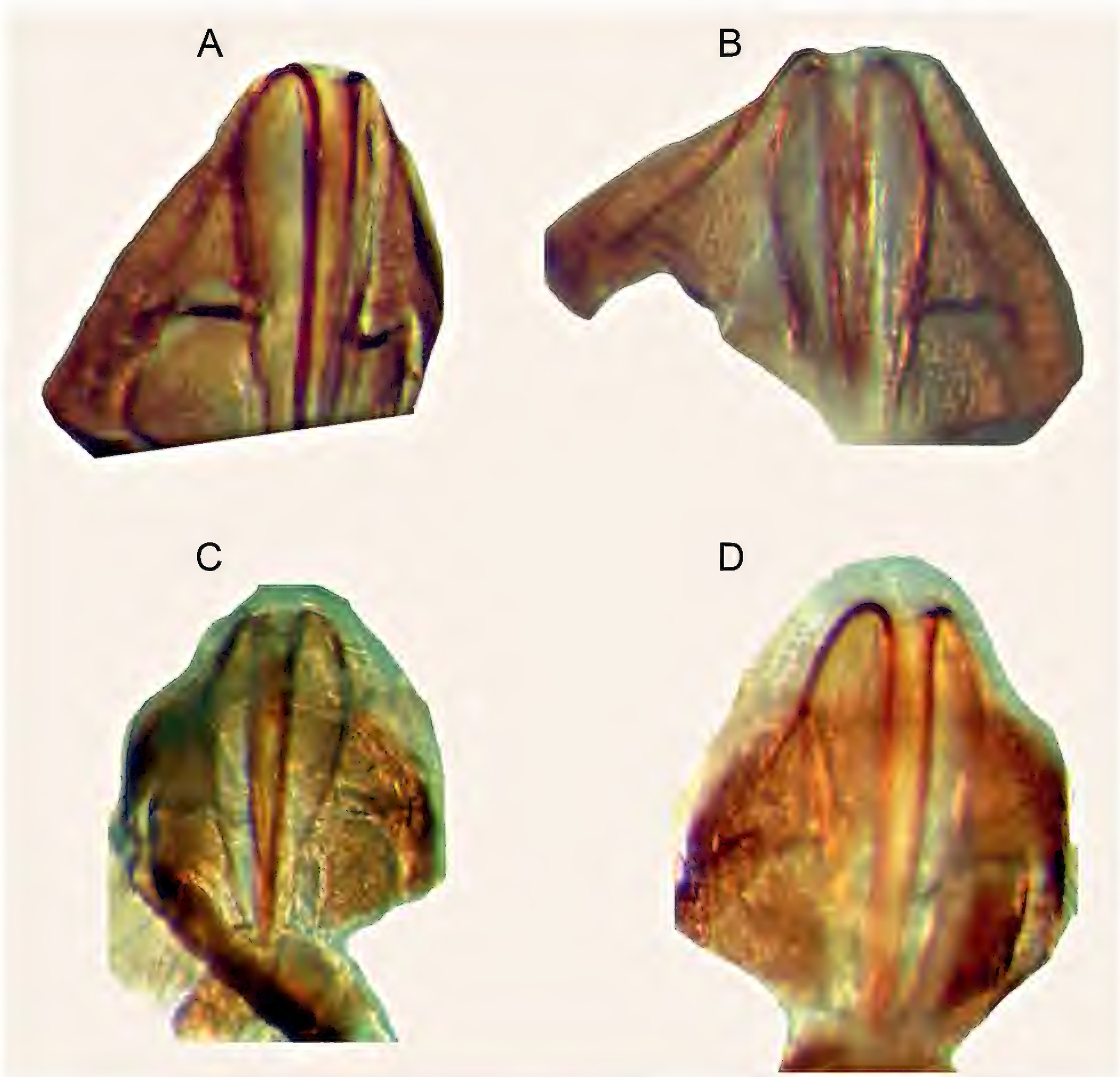


Fig. 4. *Trynocoris* spp., female genitalia in different views. **A–B**. *Trynocoris lawrencei* Herring, 1976. **C–D**. *T. costaricaensis* sp. nov.

ters and femora. ***Thorax***. Pronotum, mesoscutum and scutellum entirely black. Length of pronotum 0.50 mm, anterior margin 0.50 mm, lateral margins 0.65 mm, posterior margin 1.30 mm. Hemelytra black, covered with shining setae. Cuneus brown to dark brown tinged with orange at the base and along the external margin. Body ventrally chestnut to dark brown, coxae chestnut. ***Male genitalia*** (Fig. 2). Left paramere hook-shaped; apical process thin in lateral view, broadened basally, narrowed toward the apex, apical process broad in dorsal view, its apex curved toward the right side; paramere body with a bundle of long, thick setae dorsally, paramere body when viewed laterally with inner margin weakly convex basally and nearly straight and inner margin strongly convex medially. Right paramere C-shaped; apical process thin and curved in lateral view, in dorsal view apical process broad, nearly ellipsoid, with the moderately developed process in the medial part of the right lateral margin. Aedeagus narrow, ductus seminis thin and long, endosoma membranous.

Distribution

Costa Rica.

Biology

Unknown, but the specimens of this species were collected from a log covered with fungi. *T. lawrencei* was also collected in a similar habitat.

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Research article

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A new endemic species of pelvic-brooding ricefish (Beloniformes: Adrianichthyidae: *Oryzias*) from Lake Kalimpa'a, Sulawesi, Indonesia

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Abstract. *Oryzias kalimpaaensis* sp. nov. is a new species of the genus *Oryzias* Jordan & Snyder, 1906, endemic to Lake Kalimpa'a in Lore Lindu National Park, Central Sulawesi, Indonesia. The species is a pelvic-brooder, a non-monophyletic group of ricefishes in which females carry an egg cluster until hatching. Pelvic-brooding is known from only a few taxa, and the new species reported here is only the fifth pelvic-brooding species known so far. *Oryzias kalimpaaensis* sp. nov. differs from all others *Oryzias* species by the following combination of characters: 61–67 scales in lateral line, 11–13 dorsal-fin rays, 11–13 pectoral-fin rays, body depth 16.0–22.2% SL, and length of head 30.1–33.7% SL. It is distinguished from all species of the genus *Adrianichthys* Weber 1913, by its small size (max. 52.8 mm SL). A molecular phylogeny based on mitochondrial ND2 sequences supports the distinctiveness of *O. kalimpaaensis* sp. nov. *Oryzias kalimpaaensis* sp. nov. is closely related to pelvic-brooding *O. eversi* Herder, Hadiaty & Nolte 2012 endemic to Tilanga Pond in Tana Toraja, and to the two species of Lake Lindu in Central Sulawesi, *O. sarasinorum* (Popta 1905) and *O. bonneorum* Parenti 2008. As Lake Kalimpa'a is a popular destination for nature tourism, anthropogenic pressure is high. The presence of invasive fish species in the lake and parasites on collected specimens support thiss assumption.

Key words. Endemic, *Oryzias*, freshwater fish, Kalimpa'a, pelvic-brooder.

INTRODUCTION

Sulawesi is one of the five largest islands in Indonesia, and harbors a rich fauna of freshwater fishes, including endemic lake- and stream-dwelling species (Kottelat 1990a, 1990b; Miesen et al. 2016; Hadiaty 2018). The island is a hotspot of ricefish diversity (Adrianichthyidae; reviewed by Hilgers & Schwarzer 2019), and almost all ricefish species known from it are endemic. Distribution areas of most species are small, typically restricted to single lakes like those of the Malili Lakes system, Lake Lindu, or Lake Poso; some ricefishes are even restricted to tiny pools or ponds, or stretches of rivers (Parenti 2008; Herder & Chapuis 2010; Parenti & Hadiaty 2010; Herder et al. 2012; Parenti et al. 2013; Mokodongan et al. 2014). The genus *Oryzias* Jordan & Snyder, 1906 is the most diverse and consists of thirty-two species; four species restricted to Lake Poso make up the endemic genus *Adrianichthys* Weber, 1913.

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Fig. 1. Lake Kalimpa'a: type locality of *Oryzias kalimpaaensis* sp. nov., in Central Sulawesi, Indonesia.

Reproduction of Sulawesi ricefishes can be assigned to two general strategies, transfer-brooders, i.e., species that deposit fertilized eggs on a substrate, as it is the case with most adrianichthyids, and pelvic-brooders (Parenti 2008; Spanke et al. 2021). In pelvic-brooding ricefishes, females carry the fertilized eggs until the fry hatches, protected in a ventral concavity, and covered by elongated pelvic fins (Parenti 2008; Parenti & Hadiaty 2010; Parenti et al. 2013; Mokodongan et al. 2014; Mandagi et al. 2018; Spanke et al. 2021). Interestingly, pelvic-brooding occurs in species of both genera, *Oryzias* and *Adrianichthys*. So far, a total of four pelvic-brooding ricefishes has been reported: *A. oophorus* (Kottelat, 1990), *A. poptae* Weber & de Beaufort, 1922, *O. sarasinorum* (Popta, 1905) and *O. eversi* Herder, Hadiaty & Nolte, 2012 (Kottelat 1990a; Parenti 2008; Herder et al. 2012; Mokodongan & Yamahira 2015).

Here we describe a new species of pelvic-brooding *Oryzias* endemic to a small lake in Central Sulawesi, Lake Kalimpa'a, which is located within Lore Lindu National Park, close to Lake Lindu. This discovery brings the number of recognized ricefish species on Sulawesi to 23, including at least five pelvic brooders (Parenti 2008; Herder & Chapuis 2010; Parenti & Hadiaty 2010; Herder et al. 2012; Parenti et al. 2013; Mokodongan et al. 2014; Mandagi et al. 2018; Utama et al. 2022).

MATERIAL AND METHODS

Species description and specimens of the new *Oryzias* were collected from Lake Kalimpa'a (Fig. 1) in Central Sulawesi, at 1°19′36.1″ S, 120°18′26.1″ E, approximately 23 km east of Lake Lindu (Fig. 2). The fish were caught with a hand net 13 Sep. 2020. Immediately after capture, specimens of both sexes were photographed in a small tank to document life coloration. For morphological investigations, 18 individuals (10 males and 8 females) were anesthetized using ice slurry, preserved in 5% formalin for morphological analyses and later transferred to 70% ethanol for storage. Specimens are deposited in the fish collections of Museum Zoologicum Bogoriense (MZB), BRIN in Cibinong; Museum Koenig, Bonn (ZFMK); the Zoological Reference Collection (ZRC) of the Lee Kong Chian Natural History Museum, National University of Singapore.

Following Parenti (2008) we distinguished the specimens as genus *Oryzias* by several characters including maximum size in adult fish 52.8 mm SL. Specimens were compared to all known Sulawesi *Oryzias* species, with emphasis to those from Central Sulawesi and other pelvic-brooding species (Lake Lindu: *O. sarasinorum* and *O. bonneorum*; Tilanga Pond: *O. eversi*; Lake Poso: *O. nebulosus* Parenti & Soeroto 2004, *O. nigrimas* Kottelat 1990, *O. orthognathus* Kottelat 1990, and Lake Tiu: *O. soeroto* Mokodongan, Tanaka & Yamahira 2014). Assessment of morphological traits follows Herder et al. (2012). Number of fin rays and scales were counted directly from each individual using a stereo-microscope (SWIFT- S306S-20-2L).

To investigate phylogenetic relationships, NADH dehydrogenase subunit 2 (ND2) gene region was sequenced using two primers ND2L (5'-GGGCCCCATACCCCAAACATGTTGG-3') and ND2H (5'-TTAATTAAAGTGTCTGTTTTGC-3') following Mokodongan and Yamahira (2015). DNA was extracted from the right pectoral fin of two different uncatalogued individuals of *O. kalimpaaensis* sp. nov. using standard protocol Qiagen DNeasy Blood & Tissue Kit. PCR conditions were as following: 94 °C for 3 min for denaturation, 35 cycles

of 94 °C for 30 s, 50 °C for 30 s, and 72 °C for 60 s, with a final extension of 72 °C for 2 min. Positive amplification was verified on a 1% agarose electrophoresis gel. PCR products were then sent to PT. Genetika Science in Jakarta (http://actagen.com) for sequencing. Sequence information for the new species were aligned together with sequences of 21 other species (two *Adrianichthys* and 19 *Oryzias*) obtained from Mokodongan & Yamahira (2015); accession numbers LC051687-LC051739. Alignments were done via ClustalW ver. 1.4 (Thompson et al. 1994) and manually curated. The final alignment consisted of 1046 bp. Sequence data of *O. kalimpaaensis* sp. nov. and *O. bonneorum* were deposited in DNA Data Bank of Japan (DDBJ) with accession number LC669549-LC669550, and LC685422-LC685423, respectively. Phylogenetic reconstructions using Maximum Likelihood were performed in raxmlGUI 2.0.6 (Edler et al. 2021), following the substitution model selected as best fitting (GTR-I-G) by ModelTest-NG (Darriba et al. 2019) and with 1000 bootstrap replicates conducted. *Cololabis saira* (Brevoort 1856) (Beloniformes: Scomberesocidae) was used as outgroup with DDBJ accession number AP002932.

Taxonomy

Oryzias kalimpaaensis sp. nov.

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Lake Kalimpa'a Ricefish

Figs 3–4

Holotype

MZB. 26462 (Figs 3 (top), 4), ♂, 41.9 mm SL, Indonesia, Sulawesi Tengah, Regency of Lore Utara, District Poso, Lake Kalimpa'a, 13 Sep. 2020, Abdul Gani and Novian Suhendra.

Paratypes

MZB 26463–26466; 26528-26529, 4 ♂♂ (44.1–50.2 mm SL), 2 ♀♀ (41.1–42.4 mm SL); ZFMK ICH-128486–128492, 4 ♂♂ (43.7–49.1 mm SL), 3 ♀♀ (41.8–43.6 mm SL); ZRC 62531, 2 ♂♂ (47.3–47.6 mm SL), 2 ♀♀ (46.9–52.8 mm SL), collected with the holotype.

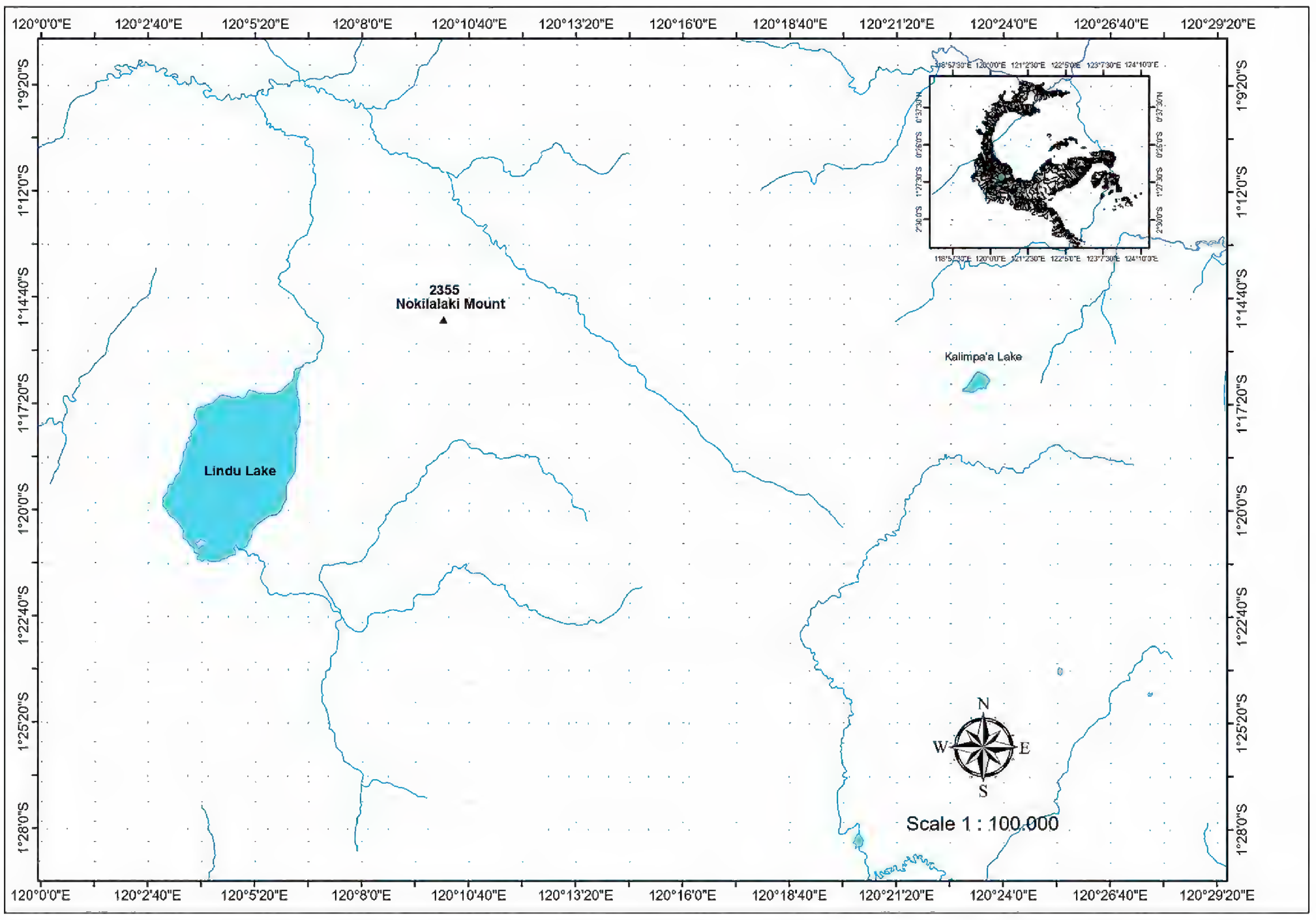


Fig. 2. Map of streams and lakes in Lore Lindu national park (Central Sulawesi, Indonesia) including the type locality of *Oryzias kalimpaaensis* sp. nov. (map by Moh. Arif Rahman). The location of the lake Kalimpa'a in Sulawesi is marked by a green dot on the map in the upper right corner.

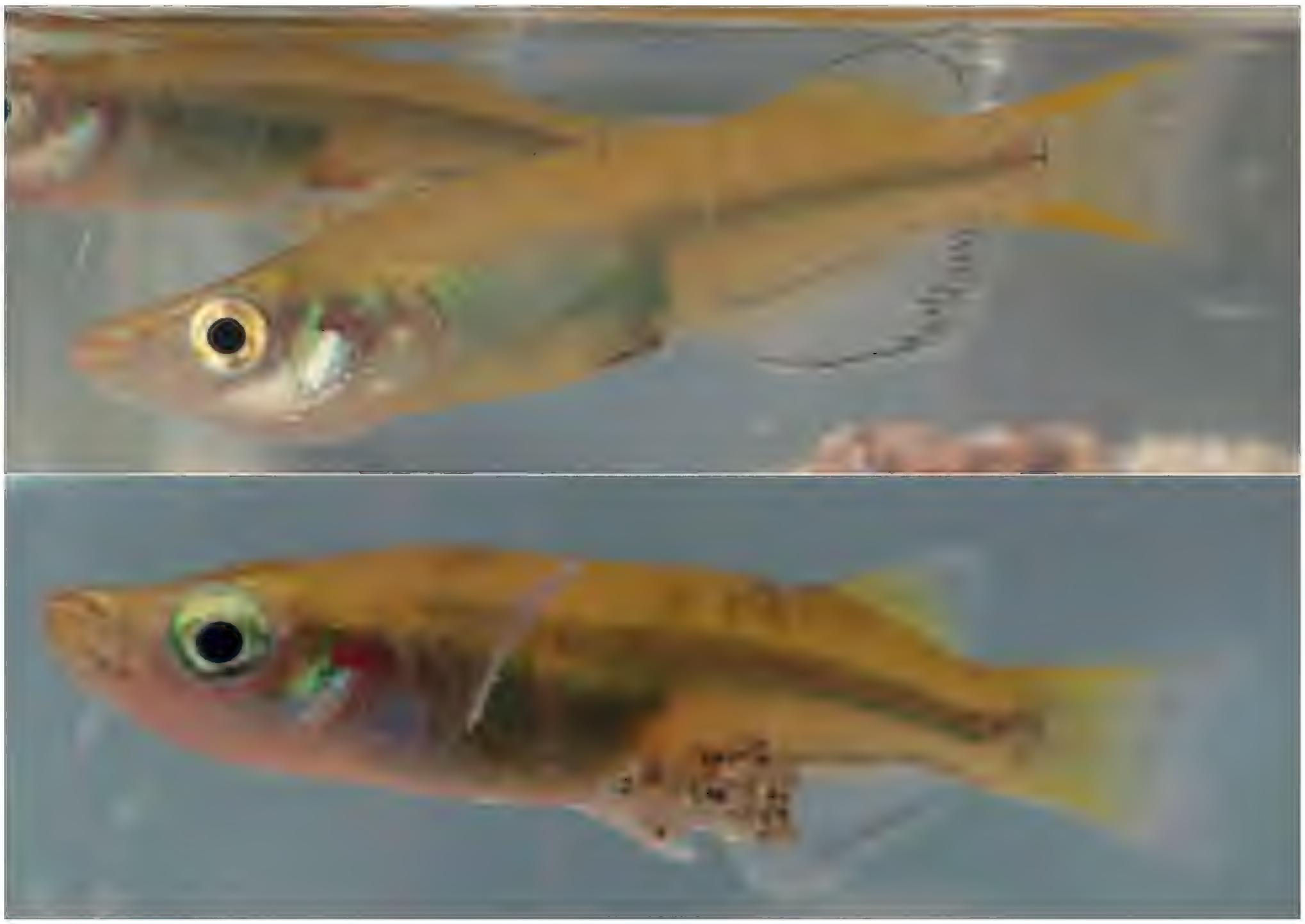


Fig. 3. Living specimens of *Oryzias kalimpaaensis* sp. nov., ♂ (top) and ♀ (bottom) from Lake Kalimpa'a, Central Sulawesi, Indonesia.

Diagnosis. *Oryzias kalimpaaensis* sp. nov. is a pelvic-brooding ricefish with pronounced sexual dimorphism. Females share with females of other pelvic-brooding ricefishes (*O. eversi*, *O. sarasinorum*, *A. oophorus*) morphological structures that enable the maternal fish to carry bundles of fertilized eggs. The eggs remain connected to the female by filaments, and are carried in a ventral concavity present in females but not in males.

Oryzias kalimpaaensis sp. nov. differs from all other *Oryzias* species from Sulawesi by unique lateral line scale counts (60–67 in *O. kalimpaaensis* sp. nov. vs. 70–75 in *O. sarasinorum*, vs. <58 in all remaining Sulawesi *Oryzias*). It has a deeper body than *O. sarasinorum* (16.0–22.2% SL vs. 13–15% SL). *Oryzias kalimpaaensis* sp. nov. has more dorsal-fin rays (11–13) than *O. hadiatyae* Herder & Chapuis 2010 (8–10), *O. celebensis* (Weber 1894) (8–10), *O. woworae* Parenti & Hadiaty 2010 (8), *O. asinua* (7–9), *O. wolasi* Parenti, Hadiaty, Lumbantobing & Herder 2013 (7–9) and *O. dopingdopingensis* Mandagi, Mokodongan, Tanaka & Yamahira 2018 (8–9), and more pectoral-fin rays (11–13) than *O. eversi* (10). In contrast to ricefishes of the *O. woworae* species group (SE Sulawesi: *O. woworae, O. asinua, O. wolasi*) *O. kalimpaaensis* sp. nov. does not exhibit red color in fins or bluish body coloration. Black blotches or lines on the lateral side of body are characteristic for *O. celebensis* (Parenti, 2008), but absent in *O. kalimpaaensis* sp. nov.. *Oryzias kalimpaaensis* sp. nov. has a relatively long head (30.1–33.7% SL) compared to *O. sarasinorum* (29% SL), *O. eversi* (28.4–30.7% SL), *O. soerotoi* (21.4–25.4% SL), *O. orthognathus* (22–26.1% SL), *O. nigrimas* (21.5–25% SL), *O. nebulosus* (23–26% SL), *O. marmoratus* (Aurich 1935) (24.0–27.2% SL), *O. matanensis* (Aurich 1935) (25–29% SL), *O. profundicola* Kottelat 1990 (22–25.4% SL), *O. celebensis* (24–26% SL), *O. woworae* (24–29% SL), *O. asinua* (25–30% SL), *O. wolasi* (25–30% SL) and *O. dopingdopingensis* (25.8–29.1% SL). Its anal-fin base is short (19.2–24.0% SL) compared to *O. soerotoi* (24.1–30.5% SL), *O. orthognathus* (26.2–31.6% SL), *O. nigrimas* (24.5–29.9% SL), *O. nebulosus* (25–29% SL), *O. marmoratus* (31.4–36.9% SL), *O. matanensis* (30.5–35.0% SL) and *O. profundicola* (37.4–41.4% SL). The snout concavity characterizing *O. hadiatyae* and *O. orthognathus* is absent in *O. kalimpaaensis* sp. nov..

Oryzias kalimpaaensis sp. nov. is distinguished from *Adrianichthys* spp. by its smaller adult body size (maximum size 52.8 mm SL, vs. 200 mm) (Parenti, 2008),



Fig. 4. Preserved specimens of *Oryzias kalimpaaensis* sp. nov., holotype (MZB 26462), ♂, 41.9 mm SL (top); paratype (MZB 26466), ♀, 42.4 mm SL (bottom).

and differs from all *Adrianichthys* except *A. oophorus* by having less anal-fin rays (20–22 vs. >23). From *A. oophorus*, it is distinguished by having more dorsal-fin rays (11–13 vs. 10) and longer head (30.1–33.7% SL vs. 25–27% SL (Parenti, 2008).

Etymology. The species epithet, '*kalimpaaensis*', denotes the occurrence of this species in Lake Kalimpa'a, Central Sulawesi, the type locality.

Description. See Fig. 3 and Fig. 4 for general appearance in lateral view and table 1 for morphometric data. Female with pronounced abdominal concavity between pelvic fin and anal fin covered by adpressed pelvic fins (11.7–19.0% SL). Body compressed laterally, body depth 16.0–22.2% SL. Caudal fin truncate; principal caudal-fin rays i,4/5,i; procurrent caudal-fin rays 6/6–6/8. Mouth supra-terminal, lower and upper jaw equal or lower jaw slightly longer than upper jaw. Length of caudal peduncle 10.3–14.4% SL, depth of caudal peduncle 10.0–12.1% SL. 11–13 dorsal-fin rays; 20–22 anal-fin rays; 5–6 pelvic-fin rays; 11–13 pectoral-fin rays.

Head length 30.1–33.7% SL and eye diameter 25.0–29.6% HL. Dorsal head profile appears slightly concave just above the orbit to the nape. Dorsal body profile relatively straight without noticeable arch from nape to dorsal-fin origin. Ventral body profile relatively straight, with slight arching from head to anal. Genital papilla single lobed in both sexes.

Live coloration. Body yellowish-brown with a brown-greenish lateral line, more pronounced in females than in males. Belly and throat light yellowish to white. 7–10 faint blackish bars on lateral side of body. Dorsal surface of head blackish, extending posteriorly as narrow black dorsal stripe to dorsal-fin origin. Opercle with silver greenish sheen. Membranes of paired and unpaired fins hyaline, rays light cream colored. Base of dorsal fin yellowish. Anal-fin base with narrow blackish stripe. Males with black submargin in dorsal and anal fin. Females with blackish submarginal band in anal fin, submarginal marking in dorsal fin black, submargin lacking in females. Caudal-fin base yellowish, followed posteriorly by a faint blackish bar. Dorsal and ventral caudal-fin margins yellowish to orange, more pronounced in males than in females. Courtship coloration unknown (Fig. 3).

Color in alcohol. Body of males and females light yellowish-brown. 7–10 faint and irregular dark brown to blackish bars on lateral body in both sexes. Males and females with a faint blackish lateral stripe on lateral midline, extending from uppermost posterior opercle to caudal-fin base. Belly blackish grey in males, whitish in females. Throat whitish in males and females. Dorsal surface of head blackish in males and females, extending posteriorly as narrow blackish dorsal stripe. Unpaired fins whitish. Anal-fin base with narrow blackish stripe. Faint blackish submargin in anal fin. Blackish submargin present in dorsal fin in males, but not in females. Base of caudal fin yellowish in both sexes (Fig. 4).

Sexual dimorphism. Females have a slightly wider body compared to males (body width: 12.3–14.1% SL in females vs. 11.7–13.4% SL in males). The single-lobed genital papilla of males is tubular and slender compared

to the more rounded female papilla. Adult males have elongated rays in dorsal and anal fin, a typical sexual dimorphism in ricefishes. Length of dorsal fin extends beyond caudal-fin base in adult males (21.2–34.4% SL in males vs. 14.4–24.9% SL in females). Elongated fin-rays are absent in dorsal and anal fins of females. Females have longer (13.7–19.0% SL vs. 10.3–12.7% SL) pelvic fins compared to males and a pronounced abdominal concavity between anal fin and pelvic fin; egg clusters in the concavity are supported by the pelvic fins (Fig. 3; Fig. 4). Due to the less pronounced concavity, males have a larger relative body depth at anal-fin origin than females (19.3–22.2% SL vs. 16.0–20.3% SL). See 'Live coloration' for coloration of male and female specimens.

Reproduction. *Oryzias kalimpaaensis* sp. nov. is a 'pelvic-brooder'. Pelvic-brooding is defined by females carrying a cluster of eggs, connected by attaching filaments to their gonoduct, until the fry hatches (Kottelat 1990a). All pelvic-brooding ricefish species described to date (*A. oophorus*, *A. poptae*, *O. eversi* and *O. sarasinorum*) share certain external female-specific morphological characteristics like elongated pelvic fins (compared to their respective males and to all transfer-brooding species) and the presence of a ventral concavity (Herder et al. 2012; Mokodongan & Yamahira 2015; Spanke et al. 2021). Female specimens of *O. kalimpaaensis* sp. nov. carry their eggs on the abdominal concavity covered by the pelvic fins. As described for the other pelvic-brooding species (Kottelat 1990a; Iwamatsu et al. 2008; Herder et al. 2012), the eggs do not adhere to each other, and are suspended by attaching filaments to the female's genital pore. Approximately 24 eggs were counted from one female specimen depicted in Fig. 4. The eggs are clearly developed and partially pigmented with embryos visible. The size of each fertilized egg is about 2.19±0.10 mm in diameter.

Distribution and habitat. *Oryzias kalimpaaensis* sp. nov. is known only from Lake Kalimpa'a, about 22 km from Lake Lindu, Central Sulawesi, situated at ca. 1,660 m above sea level. The lake is relatively small, with the longest distance across the surface being approximately 300 meters from Southwest to Northeast. The lake is used by local people as a place for nature tourism. At time of sampling, most female *O. kalimpaaensis* sp. nov. observed were carrying eggs. The lake habitat is characterized by calm water with sandy and muddy substrate with vegetation dominated by the weed *Phragmites karka* (Retz.) (Cyperales: Poaceae). The depth of Lake Kalimpa'a is about 11 meters (D. H. Kristianto & Wantoko Staff of BBTNLL, pers. comm.) and water temperature was 22 °C with pH 5–6.5 and DO 13.9 Mg/L, measured during daytime. There is a main inlet of Basakura Stream near the collection site and four more inlets of small streams around the lake. The Lake outlet is connected to the Sopu River, a tributary of the Palu River, which drains into the Makassar Strait. Other species present in the Lake Kalimpa'a were introduced african tilapia *Oreochromis* sp. (Cichliformes: Cichlidae) and snakeskin gourami *Trichopodus pectoralis* Regan 1910 (Anabantiformes: Osphronemidae), and native eel *Anguilla* sp. (Anguilliformes: Anguillidae).

Phylogenetic relationships. The resulting ML phylogeny (Fig. 5) is largely congruent with the consensus tree of Mokodongan & Yamahira (2015) in all well supported branches, including the monophyly of all known *Oryzias* species from Sulawesi (the "*Oryzias celebensis* species group"). The two *O. kalimpaaensis* sp. nov. individuals (DDBJ accession numbers: LC669549–LC669550) cluster together and form the sister-group to the two other pelvic-brooding *Oryzias* species (*O. eversi* and *O. sarasinorum*) and *O. bonneorum*. *Oryzias sarasinorum* appears paraphyletic based on our phylogeny, as one individual clusters with *O. bonneorum*. Sister-group to this clade is the river-dwelling transfer-brooding species *O. dopingdopingensis*. Interestingly, *O. bonneorum* formed a clade together with the pelvic-brooding *Oryzias* species, although it is still unclear whether this species is a pelvic-brooder or not.

DISCUSSION

Ricefishes (Beloniformes: Adrianichthyidae) are a strikingly diverse group of fishes, inhabiting riverine, lacustrine, and brackish water habitats (Parenti 2008; Hilgers & Schwarzer 2019). On Sulawesi, they show a great diversity in coloration, shape, adaptations to divergent habitat conditions and belong to two genera (*Adrianichthys* and *Oryzias*) with two main reproductive strategies: transfer-brooding and pelvic-brooding. To date pelvic-brooding is described in four species (*A. oophorus*, *A. poptae*, *O. sarasinorum* and *O. eversi*), contrasted by all other ricefish species that are either transfer-brooding or have an unknown reproductive status (i.e., *O. bonneorum, A. roseni* Parenti & Soeroto 2004 and *A. kruyti* Weber 1913). More undiscovered diversity appears likely, as ricefishes tend to inhabit small isolated habitats (see Parenti & Hadiaty 2010). Several species of Sulawesi ricefishes are known only from water bodies with small surface area, i.e., *O. soerotoi* from Lake Tiu (Mokodongan et al. 2014), *O. hadiatyae* from Lake Masapi, a small satellite lake of Lake Towuti (Herder & Chapuis 2010), *O. eversi* from Tilanga pond, a tiny karst pool (Herder et al. 2012), as well as the new species described herein.

Oryzias kalimpaaensis sp. nov. is known only from the Lake Kalimpa'a, a small upland lake at ~1660 m above sea level. This is the highest altitude at which ricefishes have so far been recorded in Sulawesi. Distance between Lake Kalimpa'a and the closest habitat of other pelvic-brooding ricefishes – Lake Lindu, the habitat of *O. sarasinorum* and *O. bonneorum* – is only ~22 km (Fig. 2). However, both are separated by a substantial

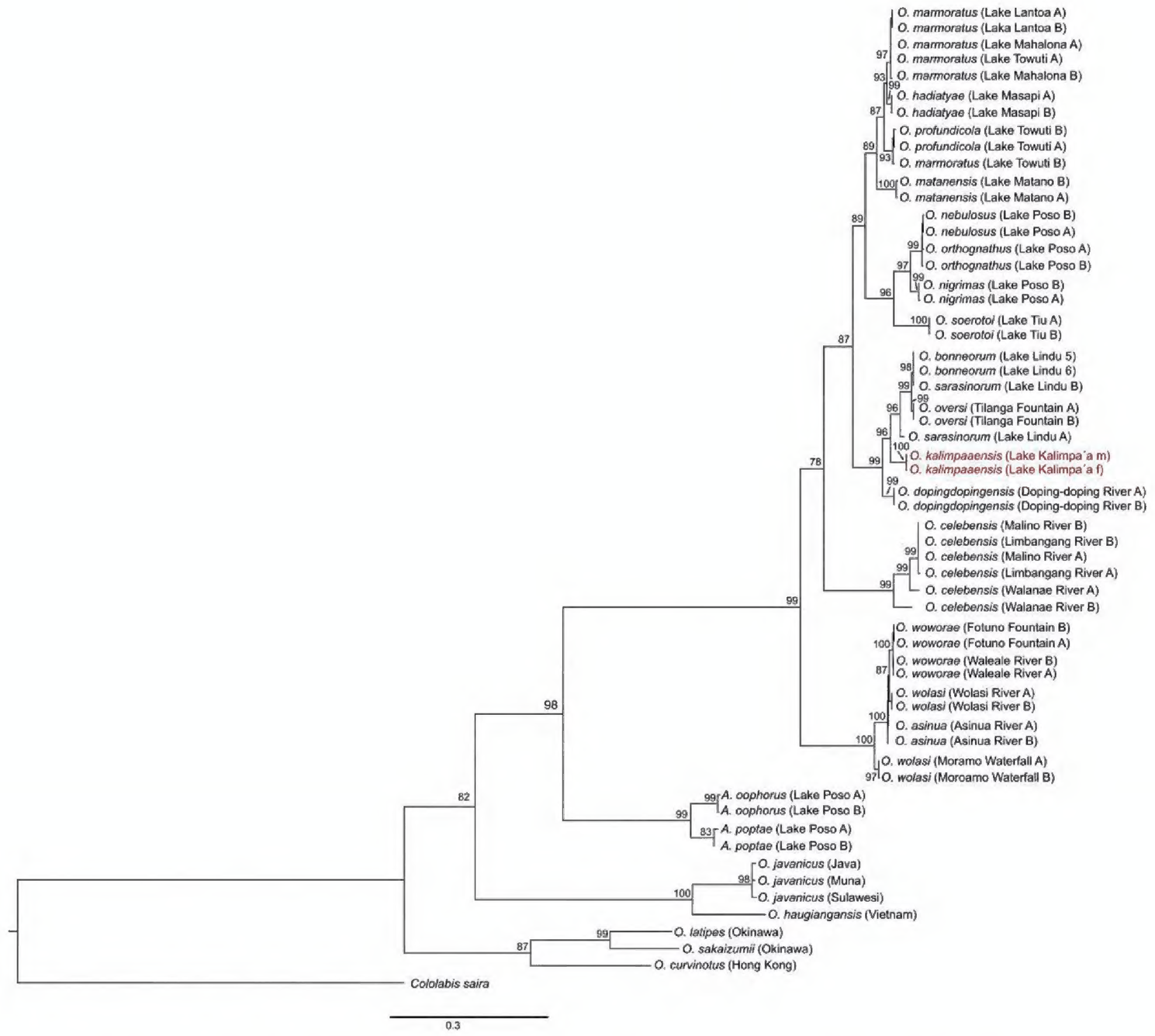


Fig. 5. Maximum Likelihood (ML) phylogenetic tree with the bootstrap values from 1000 bootstrap replicates. *Oryzias kalimpaaensis* sp. nov. is marked in red.

barrier, the Nokilalaki mountain (2357 m elevation). Geographic distance to pelvic-brooding *Adrianichthys* exceeds 56 km (Lake Poso: *A. oophorus, A. poptae*) and to *O. eversi* (Tilanga Pond) the distance is 194 km.

Based on our phylogenetic analyses, *O. kalimpaaensis* sp. nov. is closely related to both, the Lake Lindu ricefishes, and *O. eversi* (Fig. 5). Its placement within the clade of pelvic- brooding *Oryzias* appears plausible; however, the reproductive biology of *O. bonneorum* remains undocumented (Parenti 2008). The new species is distinguished from other ricefish species by several morphological characters, supporting that *O. kalimpaaensis* sp. nov. is a distinct species.

Although the reproductive ecology of *O. kalimpaaesis* sp. nov. has not been studied in detail yet, records of female *O. kalimpaaensis* sp. nov. with developing eggs on their belly (Fig. 3, Fig. 4 bottom) indicate – in line with the phylogenetic and morphological evidence – that it is a pelvic-brooding species. As in the other pelvic-brooding species, females show a set of adaptations enabling brooding, namely elongated pelvic fins, presence of a ventral concavity and long filaments attaching the eggs to the genital pore.

Lake Kalimpa'a is located in the Lore Lindu National Park, and is a popular destination for nature tourism. Protection of the flora and fauna inhabiting the lake should be implemented, especially with regard to endemic species, like *O. kalimpaaensis* sp. nov.. The most substantial threats to Sulawesi's endemic freshwater fishes are exotic fish introduction, eutrophication, overfishing, and pollution (Parenti & Soeroto 2004, Herder et al. 2022). Lake Kalimpa'a already contains non-native fishes such as African tilapia (*Oreochromis* sp.) and snakeskin gourami (*Trichopodus pectoralis*) (A. Gani & N. Suhendra, pers. obs.), which might affect together with the direct anthropogenic impact (e.g., through nature tourism) the lake flora and fauna. We found anchor worms *Lernaea* sp. in a female *O. kalimpaaensis* sp. nov., which indicates that the population might already suffer stressful conditions; parasites and disease are one of the causes of the decline in other endemic lake fishes in Sulawesi (Kottelat 1990a; Herder et al. 2022).

Comparative material examined

Oryzias asinua: MZB 21464, 2, Indonesia, Sulawesi Tenggara, District Asinua; *Oryzias bonneorum*: MZB 15499, holotype, Indonesia, Sulawesi Tengah, Lake Lindu; *Oryzias celebensis*: MZB 2688, 4, MZB 5862, 3, Indonesia, Sulawesi Selatan, Regency of Maros Indonesia; *Oryzias eversi*: MZB 20780, holotype, MZB 20781, 1 paratype, Indonesia, Sulawesi Selatan, District Rante-

Table 1. Meristic and morphometric data of *Oryzias kalimpaaensis* sp. nov. from Lake Kalimpa'a. Data of the holotype are presented in a separate column.

	males				**females**		
	holotype	**paratypes (N=10)**			**paratypes (N=7)**		
	MZB26462	**min.**	**max.**	**mode**	**min.**	**max.**	**mode**
anal-fin rays (total)	21	20	22	20	20	22	22
dorsal-fin rays (total)	12	11	13	11	11	12	12
pelvic-fin rays	5	6	6	6	6	6	6
pectoral-fin rays	13	11	13	12	12	12	12
principal caudal-fin rays	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i
procurrent caudal-fin rays	6/7	6/6	6/8	6/7	6/6	6/7	6/7
scales in lateral row	66	62	67	66	61	66	64
		min.	**max.**	**mean (SD)**	**min.**	**max.**	**mean (SD)**
standard length (mm)	41.9	44.1	50.2	47.5 (±2.2)	41.1	52.8	44.4 (±4.1)
% standard length							
total length	122.3	119.3	122.9	120.8 (±1.3)	119.0	121.9	120.1 (±1.0)
head length	33.7	30.1	33.1	31.4 (±1.0)	30.6	33.2	32.0 (±1.0)
head depth	33.7	16.7	32.1	20.7 (±5.9)	18.7	32.9	26.5 (±6.6)
head width	19.5	18.0	21.7	20.0 (±1.1)	18.5	22.4	20.0 (±1.6)
predorsal length	75.4	74.4	78.0	75.4 (±1.1)	73.3	75.9	74.9 (±1.0)
prepelvic length	49.7	49.7	51.8	50.5 (±0.8)	49.2	52.9	51.19 (±1.4)
preanal length	62.6	61.7	64.6	62.7 (±1.0)	61.8	65.7	63.29 (±1.4)
body depth	21.0	19.3	22.2	21.0 (±1.0)	16.0	20.3	18.49 (±1.5)
body width	11.7	12.1	13.4	12.7 (±0.3)	12.3	14.1	13.49 (±0.6)
length of caudal peduncle	10.6	10.3	13.3	11.9 (±1.0)	10.7	14.4	12.09 (±1.3)
depth of caudal peduncle	10.1	10.9	11.5	11.2 (±0.2)	10.0	12.1	11.09 (±0.8)
length of dorsal fin	34.4	21.2	29.1	24.5 (±2.4)	14.4	16.1	15.29 (±0.8)
length of dorsal fin base	12.8	11.3	13.9	12.7 (±0.7)	10.7	13.1	11.89 (±0.8)
length of anal fin base	23.9	19.2	24.0	22.7 (±1.4)	19.4	22.5	21.99 (±1.1)
length of pectoral fin	22.7	17.5	21.7	19.2 (±1.5)	17.3	19.8	18.69 (±0.9)
length of pelvic fin	10.6	10.3	12.6	11.4 (±0.7)	13.7	18.9	15.89 (±1.8)
% head length							
interorbital width	29.4	27.8	36.5	33.0 (±2.6)	30.6	34.2	32.79 (±1.5)
eye diameter	26.9	25.0	28.4	26.7 (±1.1)	26.3	29.6	28.09 (±1.0)
snouth length	34.7	31.5	39.2	35.5 (±2.3)	32.5	39.6	35.29 (±2.3)

pao; *Oryzias hadiatyae*: MZB 18491, holotype, MZB 18503, 1 paratype, MZB 18504, 1 paratype, MZB 18505, 1 paratype, MZB 18506, 1 paratype, Indonesia, Sulawesi Selatan, Lake Masapi; *Oryzias marmoratus*: MZB 2686, 7, MZB 2690, 1, Indonesia, Sulawesi Selatan, Lake Wawontoa; MZB 2695, 5, MZB 2697, 5, Indonesia, Sulawesi Selatan, Lake Towuti; *Oryzias matanensis*: MZB 21379, 1, Indonesia, Sulawesi Selatan, Lake Matano; *Oryzias nebulosus*: MZB 21381, 2, Indonesia, Sulawesi Tengah, Lake Poso; *Oryzias nigrimas*: MZB 5859, holotype, MZB 5872, 5 paratypes, Indonesia, Sulawesi Tengah, Lake Poso; *Oryzias orthognathus*: MZB 5870, holotype, Indonesia, Sulawesi Tengah, Lake Poso; *Oryzias profundicola*: MZB 5868, holotype, MZB 5861, 1 paratype, MZB 5866, 1 paratype, MZB 5867, 2 paratypes, Indonesia, Sulawesi Selatan, Lake Towuti; *Oryzias wolasi*: MZB 21465, 2, Indonesia, Sulawesi Tenggara, District

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Wolasi; *Oryzias woworae*: MZB 21380, 1, Indonesia, Sulawesi Tenggara, Muna Island, District Parigi.

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APPENDIX I

(*electronic supplement, available at www.zoologicalbulletin.de*)

Table S1. All measurements and counts of examined *O. kalimpaaensis*; separated in ♂♂ in ♀♀. * holotype.

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Table S1. All measurements and counts of examined *O. kalimpaaensis*; separated in ♂♂ in ♀♀. * holotype.

	males										females										
	ind 1	ind 4	ind 5	ind 9	ind 10	ind 11	ind 12	ind 13	ind 18	ind 23	**ind 19***	ind 2	ind 3	ind 7	ind 15	ind 17	ind 22	ind 25	**min.**	**max.**	**mode**
anal-fin rays (total)	20	20	20	20	21	21	22	20	21	21	21	21	21	22	22	22	20	22	20.0	22.0	21.0
dorsal-fin rays (total)	11	11	12	11	12	12	11	11	13	12	12	12	12	12	12	12	11	12	11.0	13.0	12.0
pelvic-fin rays	6	6	6	6	6	6	6	6	6	6	5	6	6	6	6	6	6	6	5.0	6.0	6.0
pectoral-fin rays	13	13	13	12	12	12	12	12	13	11	13	12	12	12	12	12	12	12	11.0	13.0	12.0
principal caudal-fin rays	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i	i.4/5.i
procurrent caudal-fin rays	6/8	6/7	6/8	6/6	6/7	6/7	6/6	6/7	6/7	6/8	6/7	6/7	6/7	6/6	6/7	6/7	6/7	6/7	6/6	6/8	6/7
scales in lateral row	66	64	65	66	66	63	62	64	67	64	66	64	65	65	64	64	61	66	61.0	67.0	64.0
																			min.	**max.**	**mean (SD)**
standard length (mm)	47.3	49.1	47.6	49.8	48.7	44.3	44.1	46.7	50.2	43.7	41.9	52.8	46.9	41.8	43.6	42.4	41.1	42.4	41.1	52.8	45.8 (±3.5)
% standart length																					
total length	122.9	122.7	119.8	121.4	119.3	119.8	120.9	119.4	120.7	121.4	122.3	120.1	119.1	120.4	120.8	119.6	122.0	119.0	119.0	122.9	120.6 (±1.2)
head length	33.1	32.3	30.3	31.6	30.4	31.7	30.1	30.4	32.1	31.6	33.7	33.2	31.8	31.7	30.6	32.6	32.9	31.0	30.1	33.7	31.7 (±1.1)
head depth	19.3	16.7	17.3	17.5	17.1	19.0	18.0	18.6	32.1	31.6	33.7	20.0	19.9	18.7	30.6	32.6	32.9	31.0	16.7	33.7	23.7 (±7.0)
head width	21.7	19.1	19.4	20.1	18.0	21.4	20.4	20.8	19.8	19.2	19.5	22.1	22.4	19.5	18.5	18.7	19.3	19.4	18.0	22.4	20.0 (±1.3)
predorsal length	78.0	74.4	75.2	75.1	74.7	75.7	76.3	74.6	74.8	75.1	75.4	73.6	73.3	75.2	74.9	75.2	75.9	75.8	73.3	78.0	75.2 (±1.0)
prepelvic length	51.6	49.9	49.9	49.7	50.5	51.8	49.7	50.0	50.7	51.6	49.7	53.0	52.5	51.1	49.9	49.2	51.9	49.9	49.2	53.0	50.7 (±1.1)
preanal length	64.6	63.2	63.3	61.7	61.9	63.8	61.7	61.9	62.9	62.3	62.6	65.7	64.3	61.9	63.8	62.9	61.8	62.2	61.7	65.7	62.9 (±1.2)
body depth	22.2	20.5	21.2	20.8	19.3	21.7	21.1	21.6	22.1	19.8	21.0	18.4	19.7	19.0	17.1	16.0	18.2	20.3	16.0	22.2	20.0 (±1.7)
body width	12.1	12.6	12.8	12.4	12.6	12.7	12.9	12.7	13.4	12.7	11.7	14.1	13.9	12.9	14.0	13.2	13.3	12.3	11.7	14.1	12.9 (±0.6)
length of caudal peduncle	10.3	12.4	11.0	12.2	10.9	13.0	13.3	12.9	11.3	11.5	10.6	10.7	11.9	10.8	14.4	11.2	12.1	12.6	10.3	14.4	11.9 (±1.1)
depth of caudal peduncle	11.2	10.9	11.5	11.4	11.0	11.2	11.3	11.3	11.4	11.1	10.1	11.9	12.1	10.5	10.9	10.0	11.1	10.3	10.0	12.1	11.1 (±0.6)
length of dorsal fin	26.0	25.8	26.3	29.1	22.7	21.3	21.2	24.3	23.9	24.9	34.4	16.1	14.8	15.8	14.4	16.1	14.5	15.0	14.4	34.4	21.5 (±5.9)
length of dorsal fin base	12.3	13.4	12.5	13.9	12.7	12.8	11.3	12.5	13.3	12.2	12.8	12.2	11.9	13.1	11.5	12.2	10.7	11.2	10.7	13.9	12.4 (±0.8)
length of anal fin base	21.7	23.1	24.0	23.8	23.8	19.2	23.1	22.3	22.8	23.3	23.9	22.5	22.0	22.4	19.4	21.9	22.5	22.2	19.2	24.0	22.4 (±1.4)
length of pectoral fin	21.2	21.7	18.8	19.7	17.5	17.9	18.2	19.6	17.7	20.2	22.7	19.1	17.3	17.7	19.8	18.4	18.9	19.2	17.3	22.7	19.2 (±1.5)
length of pelvic fin	11.2	11.2	12.3	11.5	10.9	12.7	10.6	10.3	11.6	11.7	10.6	19.0	14.3	16.0	13.7	15.7	17.4	14.7	10.3	19.0	13.1 (±2.6)
% head length																					
interorbital width	31.9	32.5	31.4	34.1	27.8	35.9	35.5	36.5	32.1	32.0	29.4	33.9	33.9	30.6	31.4	34.2	31.5	33.6	27.8	36.5	32.7 (±2.3)
eye diameter	26.1	28.2	28.0	28.4	26.4	26.2	25.6	26.3	25.0	26.8	26.9	28.0	26.3	29.6	28.8	28.0	27.4	27.7	25.0	29.6	27.2 (±1.2)
snouth length	34.0	35.7	35.9	36.3	35.2	32.4	37.1	39.2	31.5	37.6	34.7	33.9	39.7	32.5	34.7	36.6	34.1	34.8	31.5	39.7	35.3 (±2.2)